Calling songs of Neotropical katydids (Orthoptera: Tettigoniidae) from Panama

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Abstract

Understanding the ecology and evolution of animal communication systems requires detailed data on signal structure and variation across species. Here, we describe the male acoustic signals of 50 species of Neotropical katydids (Orthoptera: Tettigoniidae) from Panama, with the goal of providing data and recordings for future research on katydid communication, evolution, ecology, and conservation. Male katydids were recorded individually using an ultrasound-sensitive microphone and high-sampling rate data acquisition board to capture both audible and ultrasonic components of calls. Calls varied enormously in duration, temporal patterning, peak frequency, and bandwidth both across and within subfamilies. We confirm previous studies showing that katydid species within the subfamily Pseudophyllinae produced short calls (<250 ms) at long intervals and we confirm that this is true for species in the subfamily Phaneropterinae as well. Species in the Conocephalinae, on the other hand, typically produced highly repetitive calls over longer periods of time. However, there were exceptions to this pattern, with a few species in the Conocephalinae producing very short calls at long intervals, and some species in the Phaneropterinae producing relatively long calls (1–6 s) or calling frequently. Our results also confirm previous studies showing a relationship between katydid size and the peak frequency of the call, with smaller katydids producing higher frequency calls, but the slope of this relationship differed with subfamily. We discuss the value of documenting the diversity in katydid calls for both basic studies on the ecology, evolution, and behavior of these species as well as the potential conservation benefits for bioacoustics monitoring programs.

Keywords

Introduction

Understanding the ecology and evolution of animal communication systems requires detailed data on signals and how they vary across species (Cocroft and Ryan 1995, Endler et al. 2005, Arnegard et al. 2010, Liénard et al. 2014, Tobias et al. 2014). In many animal taxa, males produce conspicuous acoustic signals to attract females for mating (Myrberg et al. 1986, Catchpole 1987, Gerhardt and Huber 2002, Smotherman et al. 2016), providing opportunities for both basic studies on communication and applied studies through bioacoustic monitoring (Sueur 2002, Chek et al. 2003, de Solla et al. 2005, Gasc et al. 2013, Krause and Farina 2016, Grant and Samways 2016). Acoustic signal production by males is particularly conspicuous and ubiquitous in the Orthoptera (Römer 1998, Gerhardt and Huber 2002), making species in this taxon ideal for the types of studies mentioned above (e.g., Diwakar and Balakrishnan 2007a, Schmidt et al. 2012, Jain et al. 2014, Frederick and Schul 2016, Roca and Proulx 2016, Bailey et al. 2019). Here we describe male acoustic signals of 50 species of Neotropical katydids (Orthoptera: Tettigoniidae) from Panama, with the goal of providing data and recordings for future research on katydid communication, evolution, ecology, and conservation.

Katydids, also known as bushcrickets, are a highly diverse group of insects (Mugleston et al. 2018) in which males produce acoustic signals, or calls, to attract females. In most subfamilies, males call and females walk to males by tracking the source of the sound, a behavior called phonotaxis (Bailey et al. 1990, Schul and Schulze 2001, Guerra and Morris 2002, Kowalski and Lakes-Harlan 2011, Dutta et al. 2017). In the subfamily Phaneropterinae, however, males and females usually produce an acoustic duet, with the female producing a call in a short, and species-specific, latency after the male call (reviewed in Bailey 2003, Heller et al. 2015). Phaneropterine males walk to the replying female or, in some phaneropterine species, both sexes move toward each other (Heller et al. 2015). Male katydids call by rubbing a plectrum on one forewing across a file on the underside of the other forewing (Bailey 1970, Montealegre-Z and Mason 2005), a form of sound generation termed stridulation. Depending on the species, sound can be produced during wing clos-
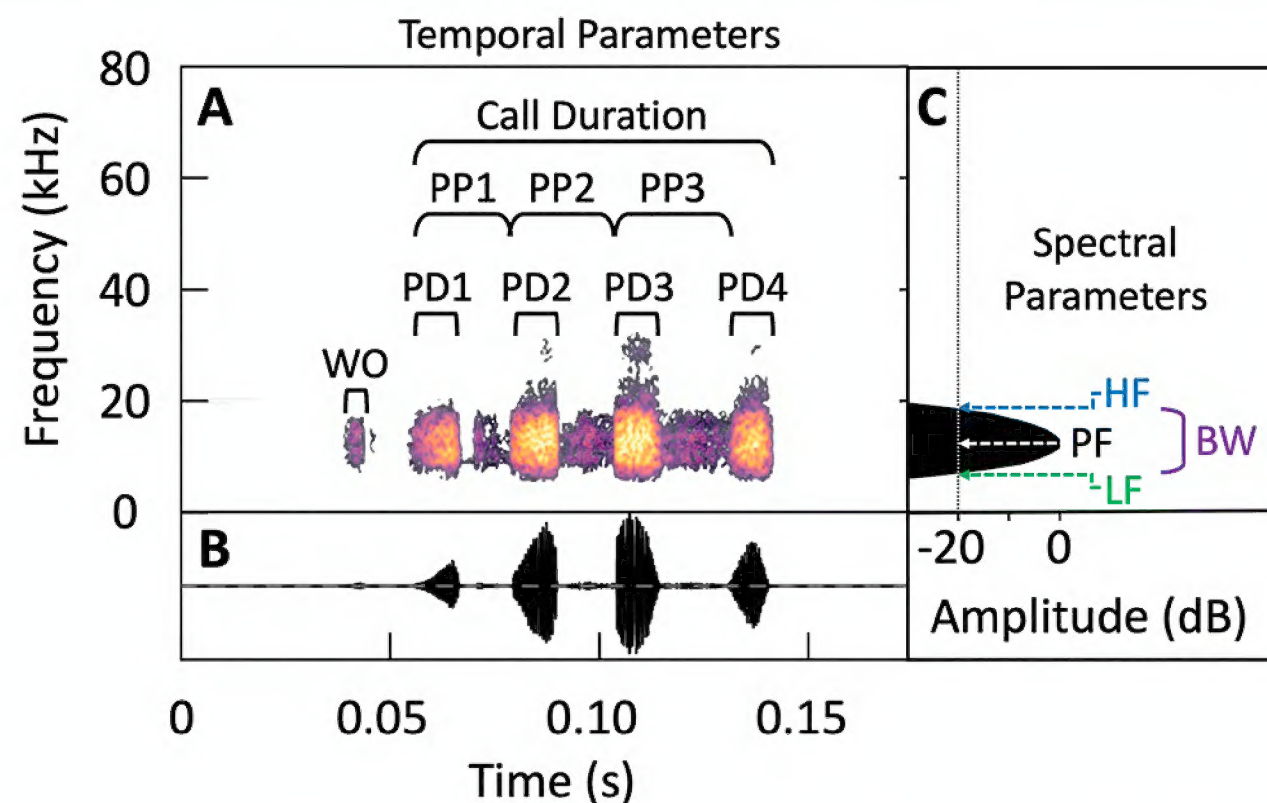
Fig. 1. Representative call of *Orophus conspersus* with labelled acoustic parameters: **A.** Spectrogram; **B.** Oscillogram; and **C.** Power spectrum. Temporal parameters – PD: pulse duration, PP: pulse period, WO: wing-opening sound. Spectral parameters – BW: bandwidth, HF: high frequency, LF: low frequency, PF: peak frequency.

ing, wing opening, or both wing opening and closing movements (Suga 1966, Morris and Pipher 1972, Walker and Dew 1972, Hartley et al. 1974, Walker 1975a, Morris and Walker 1976, Heller 1988, Montealegre-Z 2012, Stumpner et al. 2013, Chivers et al. 2014). In addition to acoustic signals, many katydid species in the subfamilies Conocephalinae and Pseuodophyllinae produce vibrational signals that travel through plants (Morris 1980, Belwood and Morris 1987, Belwood 1988a, Saul-Gershenz 1993, Morris et al. 1994, Römer et al. 2010, Stumpner et al. 2013, Sarria-S et al. 2016), and in at least one pseudophylline species, males and females perform an acoustic-vibratory duet (Rajaraman et al. 2015).

Calling songs have been described for many katydid species across the world, and the acoustic properties of these calls are extraordinarily diverse (Ragge and Reynolds 1998, Naskrecki 2000, Rentz 2001, Diwakar and Balakrishnan 2007a, Cole 2010, Cheng et al. 2016, Hemp and Heller 2017, Chamorro-Rengifo et al. 2018, Sevgili et al. 2018). Similar to crickets (Otte 1992), the temporal structure of the call usually differs between sympatric species and appears to be an important parameter for identifying a potential mate of the same species (Bailey and Robinson 1971, Tauber and Pener 2000, Deily and Schul 2004, Bush and Schul 2006, Cole 2010, Hartbauer and Römer 2014). Unlike crickets, most of which produce sounds in a relatively narrow band of frequencies between 2–8 kHz (Otte 1992, Diwakar and Balakrishnan 2007a, but see Robillard and Desutter-Grandcolas 2004, Robillard et al. 2015), katydids show enormous variation in the dominant frequency of their calls, ranging from as low as 0.6 kHz (*Tympanophyllum arcufolium* from Malaysia, Pseudophyllinae: Heller 1995) all the way up to the extreme ultrasound of 150 kHz (*Supersonus aequoreus* from Colombia and Ecuador, Meconematinae: Sarria-S et al. 2014). In the past, the high frequencies produced by many katydid species for communication required specialized and costly microphones and recording equipment, which has sometimes limited the recording and documentation of calls of these species. In recent years, more affordable equipment has become available that can record these higher frequencies (e.g., Audiomoth: https://www.openacousticdevices.info).

Katydid calls and calling behavior are shaped by many selective forces including female preferences (Bailey et al. 1990, Ritchie

1996, Dutta et al. 2017), male–male competition (Greenfield 1983, Dadour 1989), interactions between female preferences and male–male competition (Morris et al. 1978, Deily and Schul 2009, Greenfield et al. 2016), parasites and predators that eavesdrop on prey signals (Belwood and Morris 1987, Hunt and Allen 1998, Lehmann and Heller 1998, Falk et al. 2015, Lakes-Harlan and Lehmann 2015), and features of the environment that influence transmission of the signal (Greenfield 1988, Stephen and Hartley 1991, Römer 1993, Schmidt and Balakrishnan 2015). The role of predators in shaping katydid calls has been a focus of research in the Neotropics due to an endemic family of bats (Phyllostomidae) that contains several species known to eavesdrop on katydid calls to locate them as prey (Belwood 1988b, Kalko et al. 1996, Falk et al. 2015, Denzinger et al. 2018), often preying on them in very large numbers (Belwood 1988a, Römer et al. 2010, ter Hofstede et al. 2017). It has been suggested that the very low calling rate of most forest-dwelling Neotropical katydids could be a result of this intense predation pressure (Rentz 1975, Belwood and Morris 1987, Belwood 1988a, Morris et al. 1994). By documenting the calls of many sympatric Neotropical species, we hope to gain a better understanding of how these numerous selective forces interact to shape patterns of acoustic signals within a community. Future work will incorporate phylogenetic data, which is not currently available for most of these species, to assess the evolution of signal types.

In addition to being interesting animals for basic studies on the ecology and evolution of acoustic communication, the conspicuous and species-specific calls produced by katydids make them ideal animals for bioacoustic monitoring projects. Compared to birds and mammals, most insects, including Neotropical katydids, have relatively small home ranges, meaning that their population dynamics will reflect local environmental conditions and will more accurately track heterogeneous conditions across a landscape (French 1999, Lang and Römer 2008, Fornoff et al. 2012, Campos-Cerqueira et al. 2019). In addition, Neotropical katydids occur at the nexus of food webs, eating many species of plants and small prey (Coley and Kursar 2014, Symes et al. 2019) and being eaten by a diversity of predators (Belwood 1990), many of which are heavily dependent on particular sizes or species of
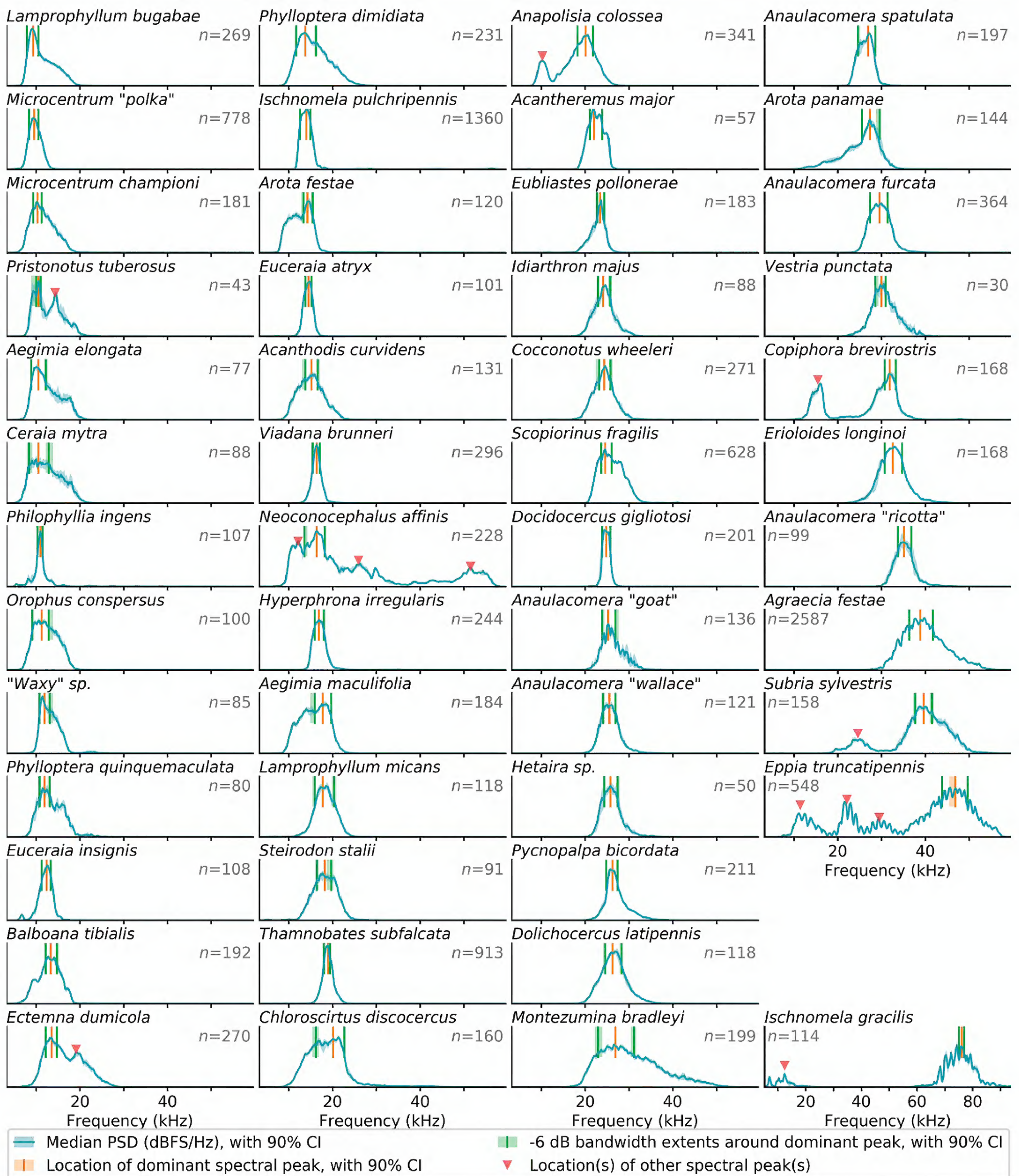
Fig. 2. Representative power spectra (dBFS/Hz) of katydid calls shown with 90% confidence intervals (CI). The number (*n*) of clips, containing calls of the focal species, used in determining the aggregated values are indicated in the respective plots. Species are arranged from lowest to highest peak frequency (top to bottom, then left to right).

Table 1. Call parameters for 50 species of katydids recorded on Barro Colorado Island, Panama. Values are mean ± standard deviation.

Species	Individuals (calls)	Call Duration (ms)	Number of Pulses in Call	Peak Frequency (kHz)	Low Frequency (kHz)	High Frequency (kHz)	Bandwidth (kHz)
Conocephalinae							
Acantheremus major	3 (7)	1,779.2 ± 1,405.7	135.0 ± 110.0	22.1 ± 0.3	20.0 ± 0.8	24.9 ± 0.6	5.0 ± 1.0
Agraecia festae	3 (15)	1,950.9 ± 373.9	26.5 ± 5.2	40.3 ± 1.4	32.1 ± 0.5	52.0 ± 2.0	19.9 ± 1.7
Copiphora brevirostris	8 (115)	30.0 ± 5.2	2.5 ± 0.4	32.9 ± 1.2	27.8 ± 0.9	34.7 ± 1.1	6.9 ± 1.5
Eppia truncatipennis	3 (11)	21,292.1 ± 8,320.1	69.6 ± 27.5	50.2 ± 2.2	37.2 ± 1.5	63.4 ± 9.0	26.1 ± 8.9
Erioloides longinoi	3 (41)	1,384.6 ± 336.1	157.9 ± 42.8	30.1 ± 1.7	25.7 ± 2.9	37.4 ± 2.4	11.7 ± 5.1
Neoconocephalus affinis	5 (25)	16,827.2 ± 7,471.4	468.1 ± 207.8	14.9 ± 2.0	9.5 ± 0.3	30.9 ± 3.0	21.4 ± 2.9
Subria sylvestris	3 (37)	125.0 ± 0.4	2.0 ± 0.0	38.9 ± 2.0	23.7 ± 6.2	49.3 ± 0.8	25.6 ± 6.8
Vestria punctata	3 (23)	31.4 ± 1.5	1.9 ± 0.1	29.7 ± 1.3	24.1 ± 2.0	36.9 ± 1.8	12.8 ± 2.9
Phaneropterinae							
Aegimia elongata - call type 1	3 (37)	204.6 ± 24.0	3.5 ± 0.5	10.2 ± 0.1	6.9 ± 0.7	20.4 ± 0.6	13.5 ± 1.1
Aegimia elongata - call type 2	2 (7)	740.2 ± 242.1	7.1 ± 1.5	10.2 ± 0.1	7.5 ± 0.3	19.9 ± 0.2	12.4 ± 0.5
Aegimia maculifolia	5 (52)	1,397.9 ± 214.7	16.2 ± 2.2	17.0 ± 1.4	10.2 ± 0.4	22.8 ± 0.4	12.5 ± 0.7
Anapolisia colossea	9 (116)	1,964.5 ± 430.0	5.6 ± 0.8	20.1 ± 0.6	12.2 ± 2.4	25.4 ± 1.0	13.2 ± 2.8
Anaulacomera furcata	3 (53)	21.2 ± 1.5	2.0 ± 0.0	29.4 ± 1.0	24.3 ± 0.8	35.9 ± 0.4	11.7 ± 0.9
Anaulacomera "goat"	3 (15)	1.7 ± 0.5	1.0 ± 0.0	27.0 ± 0.6	23.2 ± 0.6	33.0 ± 3.4	9.9 ± 3.8
Anaulacomera "ricotta"	3 (16)	59.0 ± 2.0	2.0 ± 0.0	33.8 ± 1.8	29.3 ± 2.4	39.1 ± 1.6	9.8 ± 1.5
Anaulacomera spatulata	3 (59)	43.0 ± 2.5	2.0 ± 0.0	24.5 ± 3.5	21.8 ± 3.5	29.3 ± 3.1	7.5 ± 1.3
Anaulacomera "wallace"	4 (19)	34.3 ± 2.5	3.1 ± 0.3	25.0 ± 0.6	20.4 ± 1.4	31.1 ± 3.9	10.7 ± 4.7
Arota festae	10 (83)	21.4 ± 3.2	8.0 ± 0.7	12.7 ± 1.5	7.8 ± 0.2	18.5 ± 1.1	10.7 ± 1.2
Arota panamae	10 (156)	15.3 ± 2.2	4.9 ± 0.6	24.4 ± 2.6	15.1 ± 2.3	33.2 ± 2.1	18.1 ± 3.9
Ceraia mytra	9 (71)	75.5 ± 9.4	9.7 ± 0.7	10.7 ± 0.9	6.7 ± 0.5	20.3 ± 1.2	13.6 ± 1.5
Chloroscirtus discocercus	12 (157)	139.1 ± 14.2	6.4 ± 0.5	19.2 ± 2.2	11.3 ± 0.9	25.7 ± 3.3	14.4 ± 3.8
Dolichorcercus latipennis	3 (19)	329.8 ± 26.7	15.6 ± 0.7	26.2 ± 1.0	20.9 ± 0.3	31.6 ± 1.3	10.7 ± 1.0
Ectemna dumicola	5 (83)	465.9 ± 59.0	9.9 ± 1.3	15.1 ± 2.5	10.0 ± 0.7	26.2 ± 1.8	16.1 ± 1.7
Euceraia atryx	3 (14)	1,093.2 ± 474.6	13.8 ± 2.6	13.2 ± 1.4	11.1 ± 1.1	15.9 ± 1.2	4.8 ± 0.2
Euceraia insignis	3 (21)	1,618.6 ± 266.8	16.3 ± 1.8	12.7 ± 0.7	10.3 ± 0.4	14.7 ± 0.5	4.4 ± 0.9
Hetaira sp.	3 (13)	36.2 ± 2.9	3.0 ± 0.0	24.9 ± 1.0	21.8 ± 1.2	29.5 ± 1.6	7.8 ± 0.4
Hyperphrona irregularis	3 (15)	8.8 ± 1.9	1.0 ± 0.0	16.1 ± 1.0	15.3 ± 1.1	19.2 ± 1.1	3.9 ± 0.2
Lamprophyllum bugabae	14 (207)	614.8 ± 48.3	6.9 ± 0.7	9.7 ± 0.4	7.1 ± 0.2	19.3 ± 0.8	12.2 ± 0.7
Lamprophyllum micans	11 (55)	803.4 ± 49.2	8.0 ± 0.2	17.4 ± 1.3	12.9 ± 0.6	23.8 ± 0.8	10.9 ± 0.6
Microcentrum championi	4 (20)	471.8 ± 54.1	3.1 ± 0.1	10.3 ± 0.4	6.8 ± 0.2	16.7 ± 1.5	9.9 ± 1.6
Microcentrum "polka"	8 (73)	6,322.1 ± 1,932.6	7.6 ± 1.9	9.7 ± 0.4	7.3 ± 0.3	13.6 ± 0.6	6.3 ± 0.5
Montezumina bradleyi	3 (18)	31.9 ± 6.7	1.0 ± 0.0	29.8 ± 4.7	18.7 ± 1.0	46.5 ± 3.3	27.8 ± 3.1
Orophus conspersus	4 (40)	70.4 ± 13.1	3.0 ± 0.7	11.1 ± 0.5	7.4 ± 0.5	19.0 ± 1.0	11.6 ± 1.1
Philophyllia ingens	9 (114)	6.4 ± 2.2	1.0 ± 0.0	10.8 ± 0.8	9.3 ± 1.4	13.0 ± 0.6	3.7 ± 1.4
Phylloptera dimidiata	12 (213)	20.7 ± 2.6	7.7 ± 1.1	15.8 ± 1.8	10.5 ± 1.0	25.0 ± 1.5	14.5 ± 2.0
Phylloptera quinquemaculata	3 (15)	53.1 ± 4.0	9.3 ± 1.5	11.8 ± 0.4	8.9 ± 0.3	19.8 ± 3.3	10.9 ± 3.5
Pycnopalpa bicordata	3 (14)	33.4 ± 10.1	5.0 ± 1.0	26.1 ± 0.9	22.5 ± 0.8	31.7 ± 2.4	9.2 ± 1.7
Steirodon stalii	10 (93)	208.5 ± 14.9	3.0 ± 0.0	18.6 ± 1.2	13.4 ± 1.0	24.4 ± 1.1	11.0 ± 1.4
Viadana brunneri	11 (195)	8.6 ± 0.6	2.0 ± 0.0	16.1 ± 0.5	14.7 ± 0.5	18.9 ± 0.8	4.2 ± 0.7
"Waxy" sp.	3 (13)	69.3 ± 2.3	6.5 ± 0.8	11.7 ± 0.5	9.9 ± 0.8	17.6 ± 1.1	7.7 ± 1.8
Pseudophyllinae							
Acanthodis curvidens	3 (48)	64.0 ± 7.1	5.3 ± 0.4	15.6 ± 1.0	9.6 ± 0.4	21.7 ± 1.7	12.1 ± 1.3
Balboana tibialis	4 (20)	125.3 ± 16.5	6.6 ± 1.1	14.4 ± 1.5	9.1 ± 0.9	17.5 ± 1.0	8.4 ± 1.5
Cocconotus wheeleri	6 (108)	247.3 ± 80.1	11.4 ± 3.3	24.8 ± 1.0	20.7 ± 1.0	27.4 ± 1.4	6.7 ± 1.1
Docidocercus gigliotosi	7 (140)	117.5 ± 97.0	1.6 ± 0.6	24.4 ± 0.6	23.5 ± 0.6	26.1 ± 0.8	2.6 ± 0.8
Eubliastes pollonerae	5 (100)	37.4 ± 3.1	2.0 ± 0.0	24.2 ± 1.5	21.1 ± 1.5	25.5 ± 1.7	4.3 ± 1.7
Idiarthron major	3 (26)	45.4 ± 2.1	2.0 ± 0.0	24.4 ± 0.7	19.6 ± 0.8	29.4 ± 1.9	9.8 ± 1.4
Ischnomela gracilis	4 (12)	10.8 ± 1.3	1.0 ± 0.0	73.9 ± 2.1	66.5 ± 2.9	90.6 ± 6.0	24.1 ± 7.7
Ischnomela pulchripennis	3 (15)	68.8 ± 1.8	2.0 ± 0.0	13.6 ± 0.2	12.2 ± 0.2	15.4 ± 0.2	3.2 ± 0.1
Pristonotus tuberosus	3 (9)	17.5 ± 0.8	1.0 ± 0.0	10.9 ± 1.7	8.3 ± 0.1	17.3 ± 2.8	9.0 ± 2.7
Scopiorinus fragilis	3 (15)	60.4 ± 7.3	1.0 ± 0.0	25.6 ± 0.7	21.7 ± 0.4	31.7 ± 1.0	10.0 ± 0.7
Thamnobates subfalcata	3 (15)	30.6 ± 2.8	2.0 ± 0.0	18.8 ± 0.3	17.7 ± 0.4	21.1 ± 0.7	3.4 ± 0.4

katydids (Gradwohl and Greenberg 1982, Peres 1992). Changes in vegetation or predator communities are likely to be reflected in the katydid community and changes in the katydid community will have direct impacts on vegetation and predator resources (Kalka et al. 2008). Consequently, acoustic monitoring of orthopterans is now being used as an indicator of habitat quality and change as well as for the direct conservation and management of insect populations (Fischer et al. 1997, Braun 2011a, Hugel 2012, Penone et al. 2013, Lehmann et al. 2014, Jeliazkov et al. 2016, Newson et al. 2017).

The purpose of this study was to describe the calls of many katydid species within the same community to facilitate future studies on the behavioral ecology, community ecology, conservation biology, and evolutionary biology of these insects. To this end, we provide detailed descriptions of the calls of 50 katydid species from three subfamilies (Conocephalinae, Phaneropterinae, and Pseudophyllinae) from Panama.

Methods

Katydids were collected at night from vegetation in the forest and from lights around buildings on Barro Colorado Island (BCI), Panama (9°09'53"N, 79°50'12"W), during the dry season (January to April) in 2007, 2011, 2014, and 2016–2018. We identified katydids to species, when possible, using a combination of published resources (Nickle 1992, Naskrecki 2000, Cigliano et al. 2020). Some of the species are not yet described (Robillard et al. in prep.), and to provide continuity within the literature, we use provisional manuscript 'names'; these names are disclaimed as unavailable per Article 8.3 of the ICZN. We follow the subfamilies as listed in the Orthoptera Species File (Cigliano et al. 2020), recognizing that the classifications of these higher-level taxa are unstable and currently being revised (Mugleston et al. 2013, 2018, Braun 2015a).

Katydids were housed in mesh cages with *ad libitum* water and food (cat food and apple) until recording. Male mass was determined to the nearest mg using an AWS Gemini-20 scale within 24 hours of capture. Recordings of male calls were made in a screened building close to the forest to maintain katydids at natural ambient temperature, humidity, and acoustic background, factors that appear to be important for male singing behavior. Although temperature can affect calling in katydids (Walker 1975b), the temperature and humidity of tropical rainforests is very stable compared to temperate environments. We took temperature and humidity measurements (n = 64) in the screened recording building at approximately 1800 and 0000 hours most nights. The mean temperature was 25.4 ± 1.2°C with a range of 23.0–28.7°C. The humidity was 81.3 ± 6.3% with a range of 64–92%. During call recording, individual males were placed in cylindrical metal mesh cages (72 × 150 mm, D × H) that were surrounded by acoustic foam to reduce sound reflections. A condenser microphone (CM16, Avisoft Bioacoustics, Berlin Germany) placed 30 cm from the cage, an A/D converter (UltraSoundGate 416H, Avisoft), and a laptop running Avisoft Recorder software with a sampling rate of 250 kHz were used to record calls produced by the focal male.

We quantified acoustic parameters for 2,859 calls from 265 individuals from 50 species from three subfamilies (Conocephalinae; Phaneropterinae; Pseudophyllinae). We used Avisoft SASLAB PRO acoustic analysis software (Specht 2019) to measure acoustic parameters for male calls (3–14 individuals/species, 1–20 calls/individual). Before measuring spectral parameters, we applied a frequency response filter that was the inverse of the microphone frequency response to correct for the frequency response of the microphone and generate audio files with accurate power spectra. Filtered recordings are deposited in the sound library of the Muséum national d'Histoire naturelle (MNHN: https://sonotheque.mnhn.fr/); sound inventory numbers are given as MNHN-SO*** with each species' song descriptions. Whenever possible, recorded individuals were deposited as voucher specimens in the MNHN collection for further studies. Sound recordings are also available through Dryad and GBIF. We follow the terminology and definitions for "call" and "pulse" from Morris et al. (1988). Specifically, a call is "the most inclusive repetitive time-amplitude pattern in the insect's sound emission" and a pulse is "a wave train, isolated in time by an amplitude modulation that declines to background noise level" (Morris et al. 1988). We do not have data on the wing movements during calling, preventing us from using more precise terminology (Ragge and Reynolds 1998). Most calls were also very simple and could be described without the terminology needed to describe complex calls seen in some other katydid species (Morris and Walker 1976). Very quiet sounds that consistently precede louder pulses are assumed to be wing opening sounds and are only described in cases where they are consistently long and of relatively high amplitude across individuals compared to other wing opening sound (*Acanthodis curvidens*, *Eubliastes pollonerae*, and *Vestria punctata*). Figures of example calls (oscillograms and spectrograms) were made using the R package Seewave (Version 2.0.5, Sueur et al. 2008).

Calls generally consisted of multiple short sound pulses (Fig. 1). For each call, we counted the number of pulses and measured three temporal parameters and four spectral parameters. From the oscillogram, we measured the following temporal parameters: 1) pulse durations (time from the start to the end of each pulse, in ms), 2) pulse period (time from the start of one pulse to the start of the next pulse, in ms), and 3) call duration (the time from the start of the first pulse to the end of the last pulse in the call, in ms). For spectral analyses, we used the automatic parameter measurement feature in Avisoft SASLAB PRO (FFT length 512, Hamming window, 98.43% overlap) with a spectral resolution of 488 Hz and a temporal resolution of 0.032 ms. For each individual pulse and for the entire call, we measured the following spectral parameters: 1) peak frequency (frequency with the most energy, in kHz), 2) lowest frequency (-20 dB below the peak, in kHz), 3) highest frequency (-20 dB below the peak, in kHz), and 4) bandwidth (highest frequency minus lowest frequency, in kHz). When setting the threshold for the lowest and highest frequencies, the "total" option was not selected in the automatic parameter measurement software options, which meant that additional peaks outside the main peak were not considered for lowest and highest frequencies. For most calls, this reduced the variance in the lowest and highest frequency values due to noise. A few species, however, had calls with a strong harmonic structure and multiple frequency peaks that were not included in our measurements, and for those species we describe additional frequency peaks in the text. In some cases, the automatic parameters feature included background noise as the lowest frequency, in which case, we measured the low frequency directly from the power spectrum. For each katydid species, the mean value for each call parameter was calculated by first averaging the value across calls for each individual, and then averaging across the means for each individual to calculate the mean value for the species. Standard deviations reported in the text and tables are standard deviations of the means for each individual. This was used instead of pooled means and standard deviations to reflect variation across individuals.

In addition to the measurements described above, we estimated spectral profile curves using both analyzed and additional recordings to visualize the variation in frequencies produced by species in this community (Fig. 2). All recordings (except those of *Ischnomela gracilis*) were band-pass filtered between 3.2–59.6 kHz and downsampled to 120 kHz. These parameters ensure modest amounts of data reduction and noise suppression without affecting the signals of interest. For *Ischnomela gracilis*, since the dominant frequency was between 70–80 kHz, the upper extent of the band-pass filter was set to 93.75 kHz and the recordings were downsampled to 187.5 kHz. Following resampling, the recordings were split into 1 s clips with an overlap of 12.5%. The clips were screened to retain only those that contained calls of the focal species. The waveforms in the resulting clips for each species were scaled to fit the amplitudes in the range [-1.0, 1.0], and then power spectral density (PSD) spectrograms were computed using short-time discrete Fourier transforms (using 4.25 ms Hann windows with 50.5% overlap). The ensuing time and frequency resolutions were 2.1 ms and 234.4 Hz, respectively. The lower extent of the dynamic range of the spectrograms was restricted to -60 dBFS/Hz. Representative spectral profiles of the call(s) contained in each clip were extracted by taking the maxima from each frequency bin. Since each clip is dominated by the call(s) of focal species, the representation is indicative of the true spectral profile. The representative spectral profiles were normalized to suppress effects of amplitude and background level differences between clips, and they are presented as aggregations of the per-species representative spectral profiles.

Results

Conocephalinae

Acantheremus major Naskrecki, 1997
Fig. 3 [MNHN-SO-2019-206, -207, -208]

Acantheremus major is a mid-sized (0.57 g, n = 1), light green katydid with a broad and flat face, a prominent pointed cone on its head (an elongated fastigium), and black mouthparts (Fig. 3A, B). This species is only known from Panama (Cigliano et al. 2020).

The call consists of a rapid series of pulses (Fig. 3C, D), with a total call duration that is highly variable, ranging from 0.2–4.8 s with a mean of ~1.8 s (Table 1). The peak frequency of the entire call is 22 kHz with a -20 dB frequency range spanning 20–25 kHz, giving a bandwidth of 5 kHz (Table 1). The amplitude of the pulses varies across the call. In one individual, the amplitude always increased across the call, whereas in a second individual, amplitude increased and then decreased across the call (Fig. 3C).

The pulses in the call are all very similar in their temporal and spectral properties. Pulse durations are 7.1 ± 1.5 ms (mean ± SD; 3 individuals, 7 calls, 68 pulses) and pulse periods are 15.9 ± 5.3 ms. The peak frequency of the pulse is 22.2 ± 0.3 kHz with a -20 dB frequency range spanning 20.6 ± 0.7–24.8 ± 0.9 kHz, giving a bandwidth of 4.2 ± 1.1 kHz, similar to values taken for the call as a whole (Table 1). Each pulse is very slightly frequency modulated, sweeping from ~24 to ~21 kHz (Fig. 3D). All three recorded individuals were similar in call spectral properties, but two individuals produced longer duration pulses (mean 7.7 and 8.2 ms) with shorter periods (12.3 and 13.4 ms) than the third individual (mean duration 5.5 ms, period 22.0 ms).

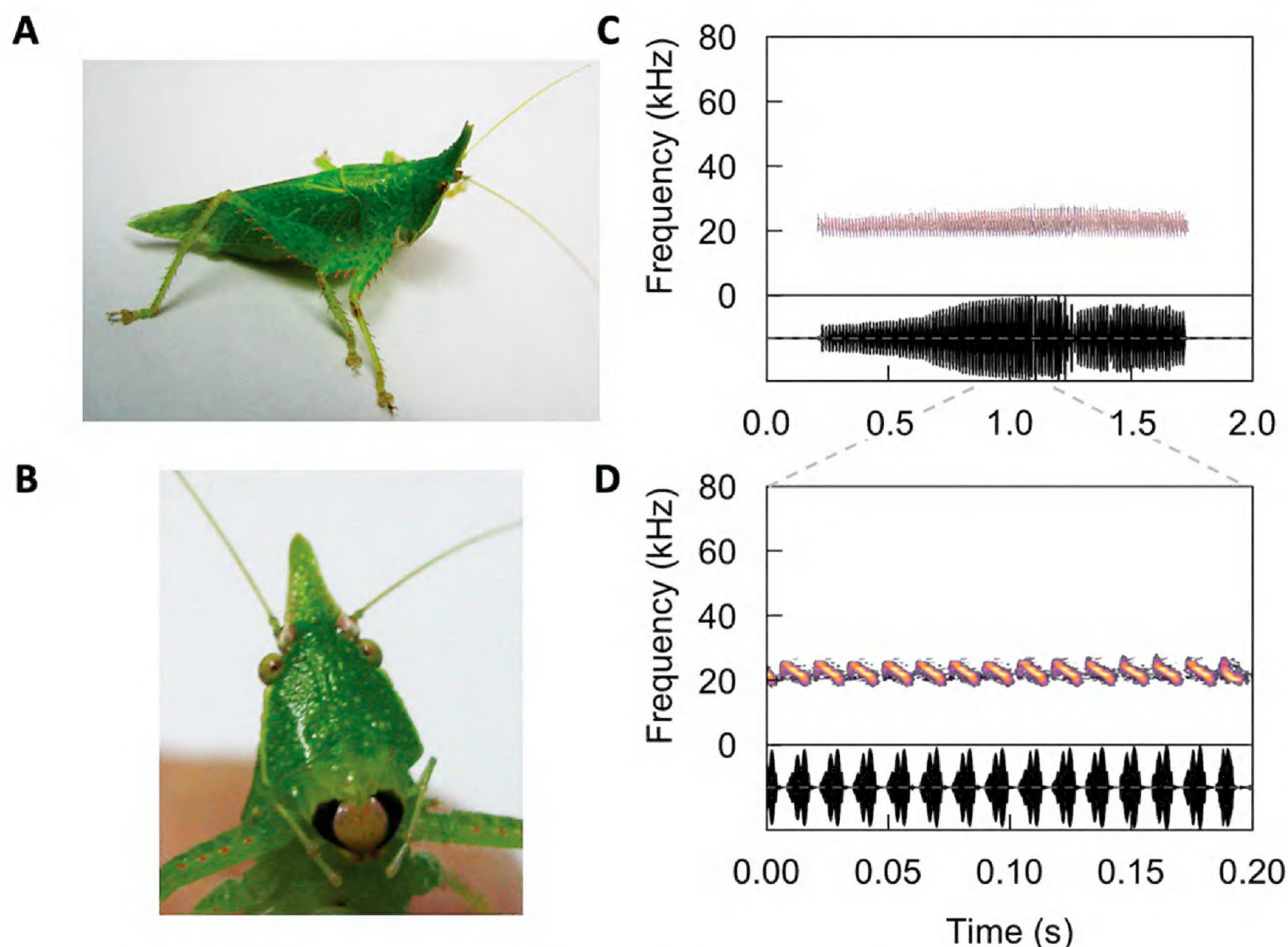This appears to be the first description of the call of this species.

Fig. 3. Photographs and calling song spectrograms of *Acantheremus major*. **A.** Male; **B.** Face; **C.** and **D.** Spectrogram (top panel) and oscillogram (bottom panel) of one call (**C**) and 14 pulses from the same call (**D**). Photo credit: H. ter Hofstede.

Agraecia festae **Griffini, 1896**
Fig. 4 [MNHN-SO-2019-220, -221, -222]

Agraecia festae is a very small (0.20 ± 0.04 g, n = 18), light green katydid with nearly translucent areas on the body and mouthparts that are red and yellow (Fig. 4A). This species was originally described by Griffini (1896), but the type specimens are currently unavailable for examination. Chamorro-Rengifo et al. (2015) treat it as *incertae sedis* and suggest that it could be transferred to another genus. This species is only known from Panama (Cigliano et al. 2020).

The call consists of a rapid series of pulses (Fig. 4B, C) with a total call duration that is highly variable, ranging from ~1–3.5 s

with a mean of ~2 s (Table 1). The peak frequency of the entire call is 40 kHz with a -20 dB frequency range spanning 32–52 kHz, giving a bandwidth of 20 kHz (Table 1). The amplitude of the pulses is similar across the call, although the first few pairs of pulses are usually of a lower amplitude than the rest of the pulses in the call (Fig. 4B). Individuals will call frequently at night and are commonly recorded in the forest on BCI.

Pulses are arranged in pairs, and individual tooth strikes are visible on the oscillogram (Fig. 4B, C). The duration of the first pulse in a pair is shorter than the second pulse (Table 2). The spectral properties of each pulse type are the same (Table 2).

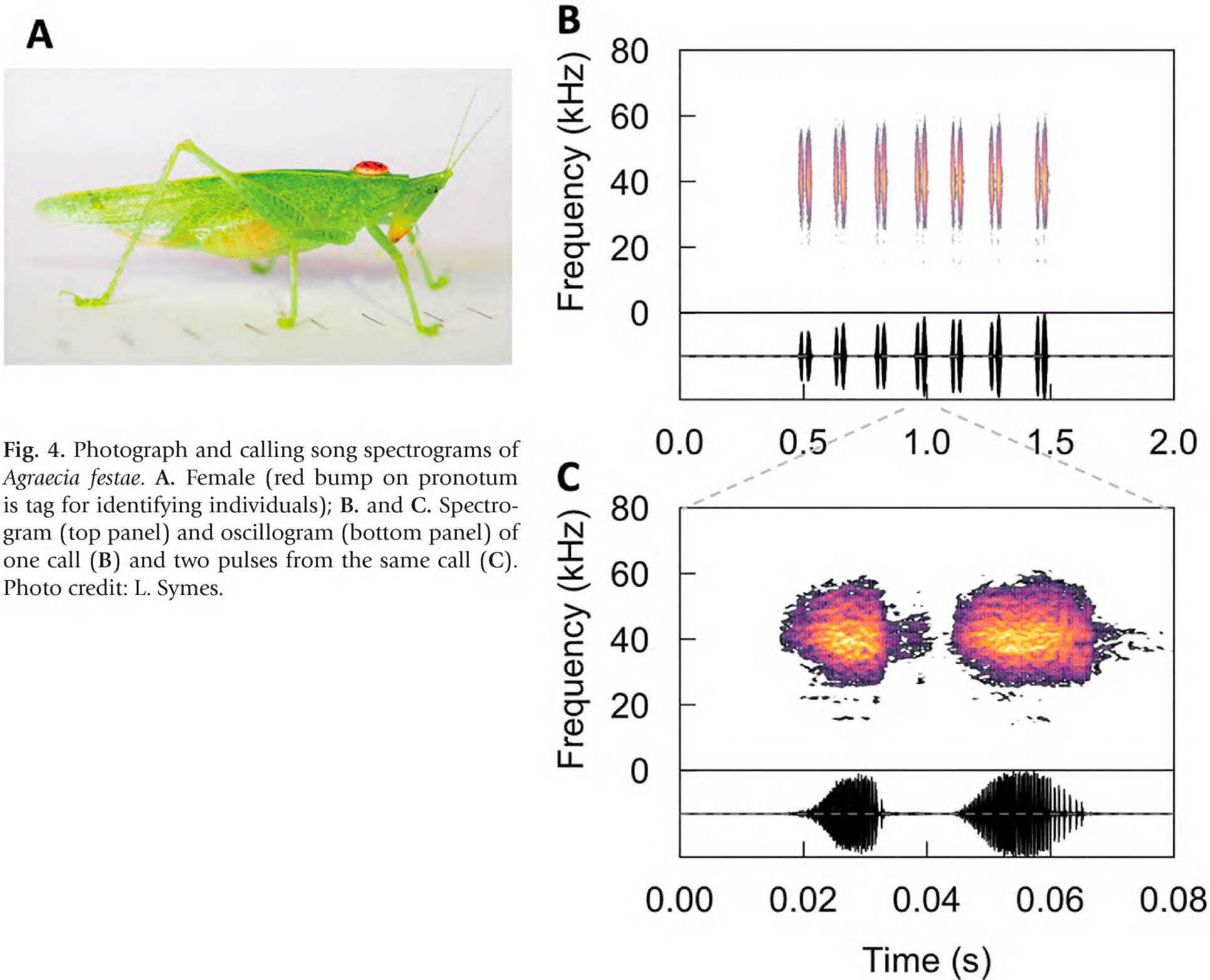This appears to be the first description of the call of this species.

Fig. 4. Photograph and calling song spectrograms of *Agraecia festae*. **A.** Female (red bump on pronotum is tag for identifying individuals); **B.** and **C.** Spectrogram (top panel) and oscillogram (bottom panel) of one call (**B**) and two pulses from the same call (**C**). Photo credit: L. Symes.

Table 2. Call pulse parameters of *Agraecia festae* (3 individuals, 15 calls; mean ± SD); n = number of pulses measured.

Pulse Type (n)	Pulse Duration (ms)	Pulse Period (ms)	Peak Frequency (kHz)	Low Frequency (kHz)	High Frequency (kHz)	Bandwidth (kHz)
1 (199)	14.7 ± 1.1	129.7 ± 7.7	40.0 ± 0.7	33.0 ± 0.8	50.4 ± 1.9	17.3 ± 1.9
2 (199)	22.3 ± 3.1	26.0 ± 2.8	39.8 ± 0.8	32.0 ± 0.5	51.1 ± 1.9	19.1 ± 1.8

Copiphora brevirostris Stål, 1873
Fig. 5 [MNHN-SO-2019-329, -330, -331, -332,
-333, -334, -335, -336]

Copiphora brevirostris is a large (1.63 ± 0.31 g, n = 51), green katydid with a broad, flat, and yellow face and a powerful bite (Fig. 5A, B). Unlike many other species of *Copiphora*, the fastigium is not elongated (i.e., no cone-like structure on the top of the head). In females, the ovipositor is longer than the body (Fig. 5B). This species is known from Panama (Nickle 1992) and Colombia (Cigliano et al. 2020).

The call consists of 1–4 pulses (Fig. 5C, D) with a mean call duration of 30 ms (Table 1). Pulses usually increase in amplitude across the call, and relatively high-amplitude wing-opening sounds can be seen before some pulses (Fig. 5D). The call has strong harmonics with the fundamental (~16 kHz) and first harmonic (~33 kHz) produced at similar amplitudes (Fig. 2). The first harmonic usually has more energy than the fundamental, but in some calls the fundamental can be the same or slightly higher in amplitude than the first harmonic. The peak frequency of the harmonic is 33 kHz with a -20 dB range spanning ~28–35 kHz, giving a bandwidth of 7 kHz (Table 1). Males call very rarely and tend to call more frequently after midnight.

Pulse durations are typically 6–9 ms (Table 3), although pulse durations are highly variable and can range from 2–12 ms. The second pulse is often slightly longer than the first pulse. Pulse periods are ~15 ms (Table 3). The spectral properties of the individual pulses are very similar to each other and the entire call (Table 3). The peak frequency of the fundamental is ~16 kHz, and the first harmonic is ~32 kHz, with a -20 dB range spanning 29–34.5 kHz, giving a bandwidth of 5.5 kHz (Table 3). The bandwidth reported here is just for the first harmonic. The fundamental was usually of a lower amplitude than the first harmonic, but the difference in amplitude was highly variable across calls and pulses. Each pulse is frequency modulated, either sweeping from higher to lower frequencies (~34 to 30 kHz) or shaped like an upside-down U (ranging from ~33 up to 35 and down to 30 kHz; Fig. 5D).

Calls of this species were previously described by Belwood and Morris (1987), Belwood (1988a), Morris et al. (1994), Falk et al. (2015), and Symes et al. (2016). In addition to acoustic signals, both males and females produce vibrational signals (described in Belwood 1988a).
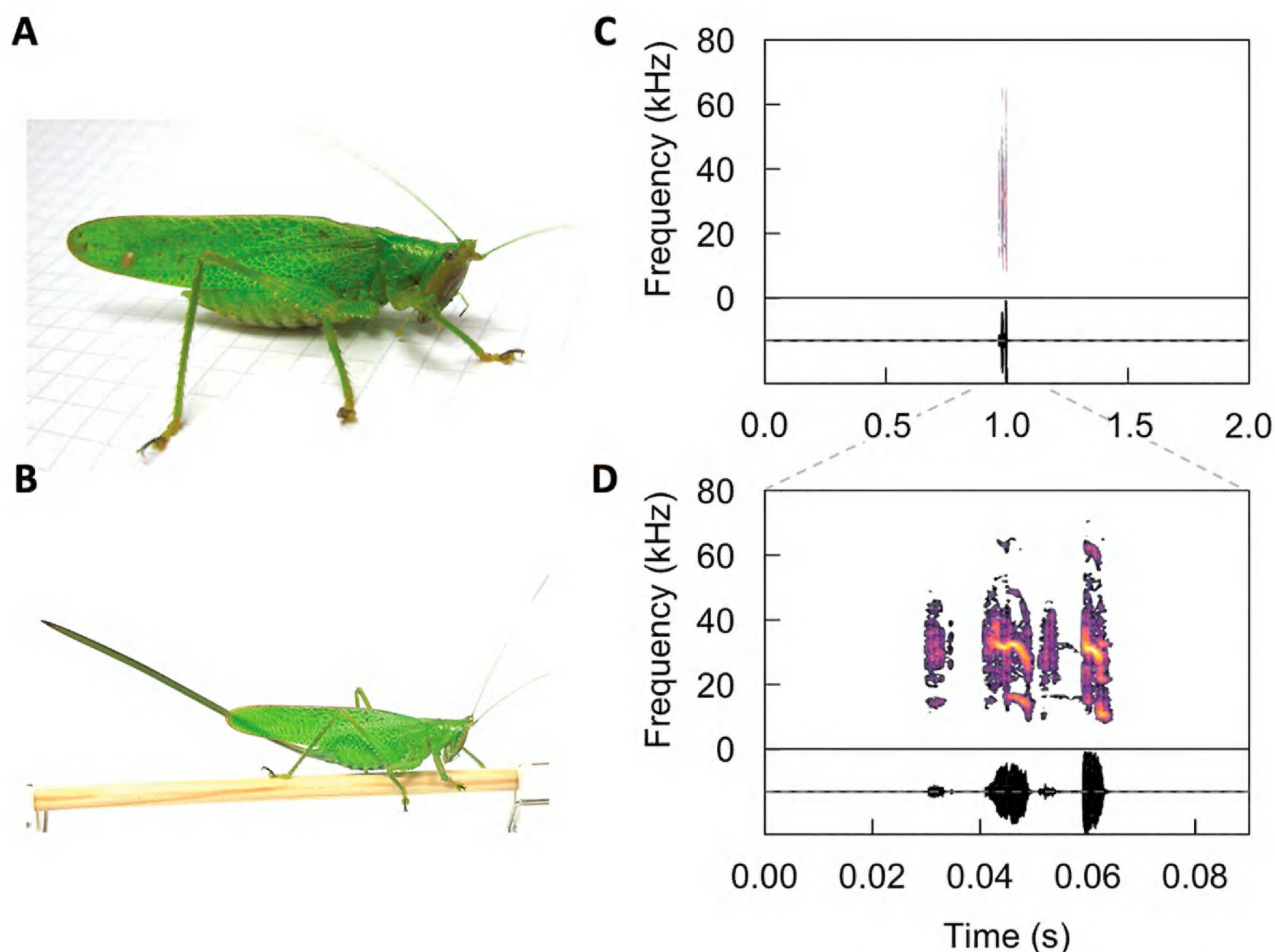

Fig. 5. Photographs and calling song spectrograms of *Copiphora brevirostris*. **A.** Male (photo credit: H. ter Hofstede); **B.** Female (photo credit: C. Wilson); **C.** and **D.** Spectrogram (top panel) and oscillogram (bottom panel) of one call at different time scales.

Table 3. Call pulse parameters of *Copiphora brevirostris* (8 individuals, 115 calls; mean ± SD); n = number of pulses measured.

Pulse Number (n)	Pulse Duration (ms)	Pulse Period (ms)	Peak Frequency (kHz)	Low Frequency (kHz)	High Frequency (kHz)	Bandwidth (kHz)
1 (115)	6.7 ± 1.7		32.9 ± 1.2	29.8 ± 1.7	34.7 ± 1.2	5.0 ± 2.3
2 (113)	8.4 ± 1.5	13.6 ± 1.9	32.7 ± 1.0	29.1 ± 1.5	34.2 ± 1.2	5.1 ± 1.8
3 (55)	7.0 ± 1.4	16.0 ± 1.4	31.2 ± 1.2	26.6 ± 1.8	34.0 ± 2.4	7.4 ± 3.6

Eppia truncatipennis Stål, 1875
Fig. 6 [MNHN-SO-2019-611, -642, -646]

Eppia truncatipennis is a large (1.18 ± 0.15 g, n = 2), mottled, brown katydid with abruptly truncated wings, a black face, and red mouthparts (Fig. 6A). This species was redescribed by Naskrecki (2000). It is known from southern Mexico, Costa Rica, Panama, and Colombia (Cigliano et al. 2020).

The call consists of a sequence of "chirps" (term used in Naskrecki 2000) composed of 10–12 pulses produced with almost no silence between them (Fig. 6B, C). Chirps are produced at very regular intervals, with a chirp period of ∼280 ms (Table 1). Sequences of chirps are produced for long periods of time (11.3–44.7 s with a mean of 21.3 s; Table 1). The peak frequency of an entire sequence of chirps is ∼50 kHz with a -20 dB frequency range spanning ∼37–63 kHz, giving a bandwidth of ∼26 kHz (Table 1).

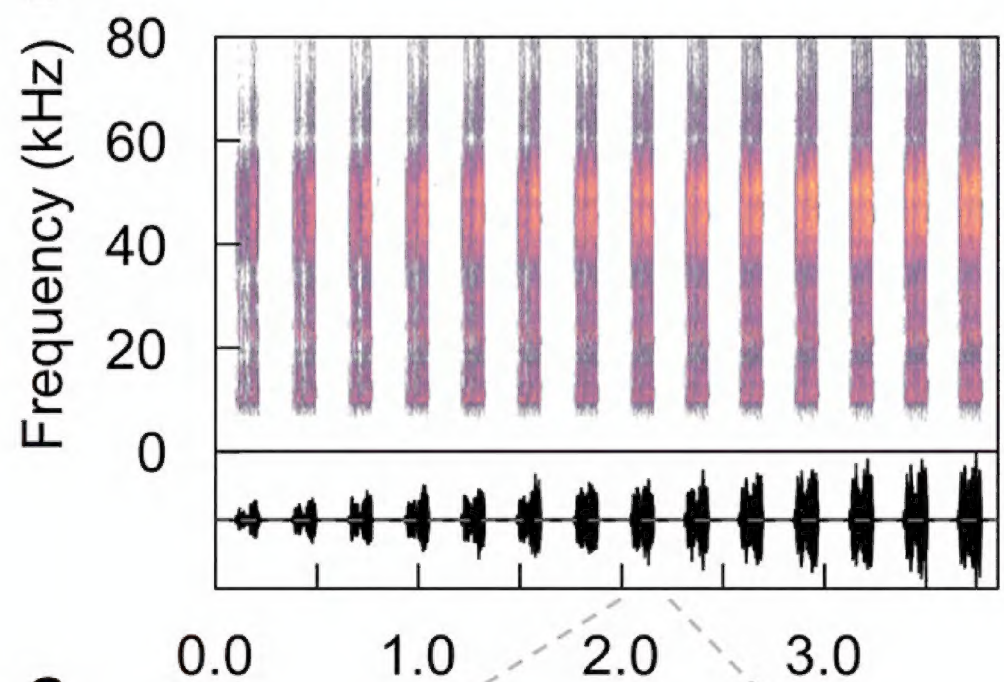The chirps are all very similar in their temporal and spectral properties. Chirp durations are 114.4 ± 9.1 ms (3 individuals, 11 calls, 110 chirps). There is always an even number of pulses within a chirp, usually 10 or 12 (mean 11.4 ± 1.1). Pulse durations within a chirp range from ∼7–14 ms. It is possible that sound is produced both during the wing opening and wing closing movements, resulting in pulses that vary in amplitude but have almost no silence between them (Fig. 6C). High-speed video of males singing would be helpful in confirming that this is the mechanism responsible for these chirps that lack silence between pulses.

The peak frequency of the chirps is 49.7 ± 2.5 kHz with a -20 dB frequency range spanning 37.5 ± 1.2–63.0 ± 8.3 kHz, giving a bandwidth of 25.5 ± 8.1 kHz (3 individuals, 11 calls, 110 chirps). There is also significant energy at 10–12 kHz, and, in some calls, this frequency range is the same or greater in amplitude than the typical peak frequency of ∼50 kHz.

Calls of this species were previously described by Naskrecki (2000), but they were recorded at a lower sampling rate that did not capture the higher frequencies described here.

Fig. 6. Photograph and calling song spectrograms of *Eppia truncatipennis*. **A.** Male (photo credit: L. Symes); **B.** and **C.** Spectrogram (top panel) and oscillogram (bottom panel) of the start of one call (**B**) and one chirp from the same call (**C**).
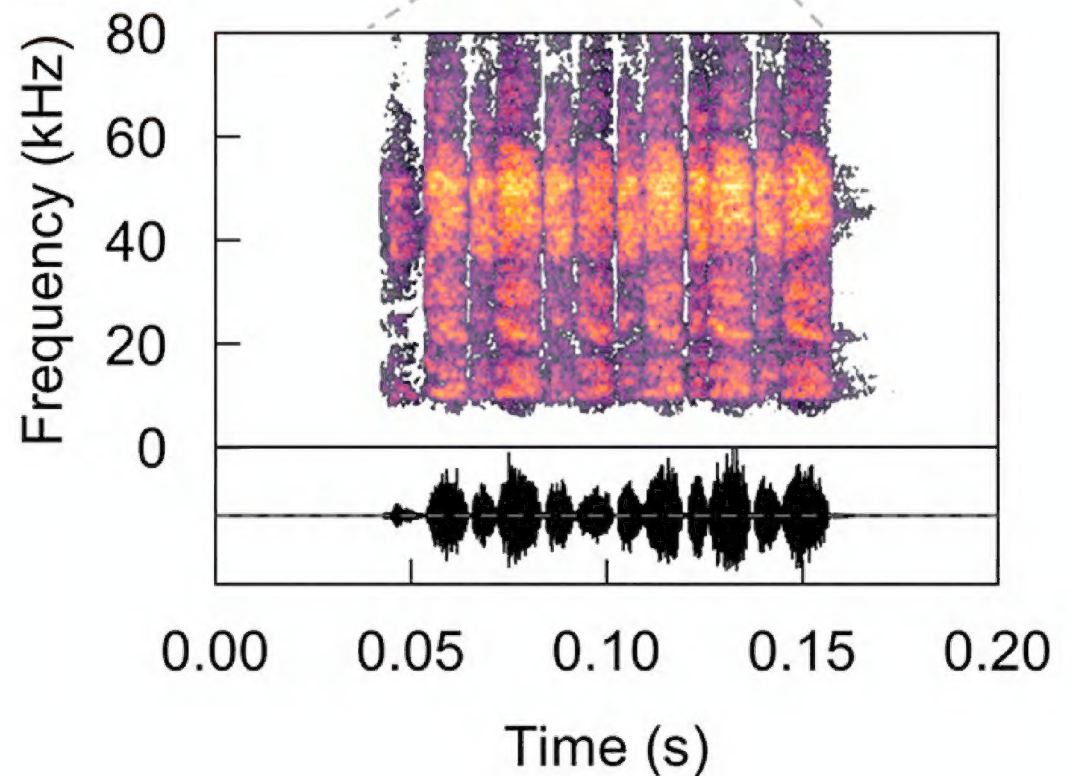
Erioloides longinoi **Naskrecki & Cohn, 2000**
Fig. 7 [MNHN-SO-2019-649, -650, -651]

Erioloides longinoi is a small (0.36 ± 0.07 g, n = 8), cylindrical, green katydid with blue mouthparts, red and yellow markings on the ventral surface of the abdomen, and an agile bite (Fig. 7A, B). This species is known from Mexico, Costa Rica, and Panama (Cigliano et al. 2020).

The call consists of a rapid series of pulses (Fig. 7C, D) with a total call duration ranging from 1.0–1.9 s and a mean of 1.4 s (Table 1). The peak frequency of the entire call is 30 kHz with a -20 dB frequency range spanning 25–37 kHz, giving a bandwidth of 12 kHz (Table 1). The amplitude of the pulses gradually increases for the first 10–15 pulses and then remains constant for the rest of the call (Fig. 7C).

The pulses in the call are all very similar in their temporal and spectral properties. Pulse durations are 4.4 ± 0.7 ms (3 individuals, 41 calls, 410 pulses) and pulse periods are 8.9 ± 0.5 ms. The peak frequency of the pulse is 30.2 ± 1.9 kHz with a -20 dB frequency range spanning 26.6 ± 2.9–38.2 ± 4.3 kHz, giving a bandwidth of 11.6 ± 7.2 kHz. Each pulse is frequency modulated, sweeping from ~32 to 28 kHz (Fig. 7D).

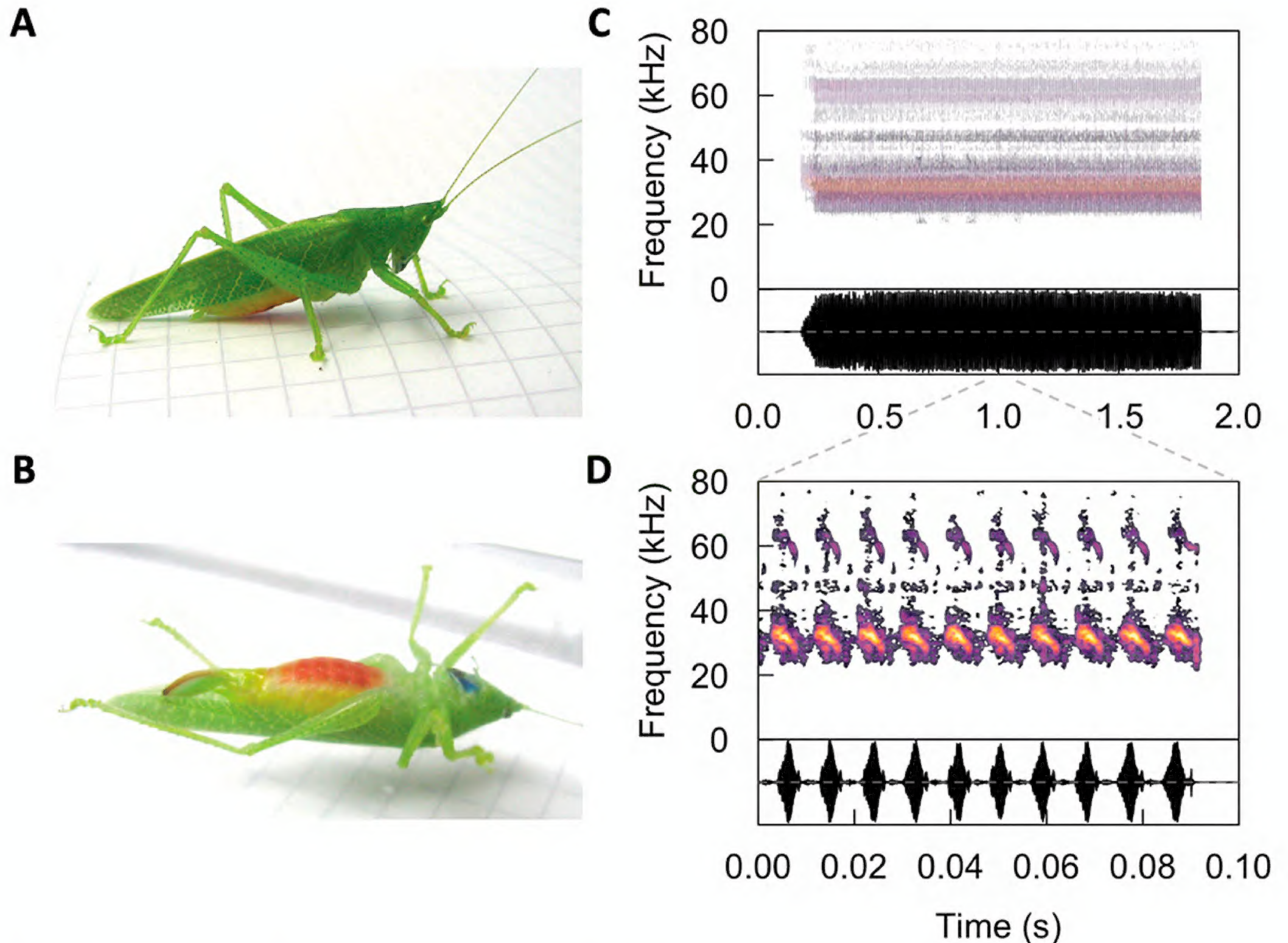This appears to be the first description of the call of this species.

Fig. 7. Photographs and calling song spectrograms of *Erioloides longinoi*. **A.** Male; **B.** Female hanging upside down from a plexiglass plate, showing coloration of abdomen and mandibles; **C.** and **D.** Spectrogram (top panel) and oscillogram (bottom panel) of one call (**C**) and 10 pulses from the same call (**D**). Photo credit: H. ter Hofstede.

Neoconocephalus affinis **(Palisot de Beauvois, 1805)**
Fig. 8 [MNHN-SO-2019-1458, -1465, -1466, -1467, -1468]

Neoconocephalus affinis is a mid-sized (0.76 ± 0.10 g, n = 4), cylindrical, green katydid with an elongated fastigium (Fig. 8A). This species is polymorphic, with both green and brown individuals observed at BCI. The species was redescribed by Naskrecki (2000). This species is known from the United States (Florida), southern Mexico, the Caribbean, Costa Rica, Panama, and northern South America (Nickle 1992, Cigliano et al. 2020).

The call consists of a rapid series of pulses (Fig. 8B, C) that can last just a few seconds or continue for many minutes continuously. Total call duration for the calls analyzed here ranged from 0.5–106 s, with a mean of ~17 s (Table 1). The peak frequency of the entire call is ~15 kHz with a -20 dB range spanning ~10–30 kHz, giving a bandwidth of ~20 kHz (Table 1). The call also has significant energy at higher frequencies in the range of 50–60 kHz (Fig. 8B, C).

Pulses are arranged in pairs and individual tooth strikes are visible on the oscillogram (Fig. 8C). The duration of pulse type 1 is shorter and usually lower amplitude than pulse type 2, and the period between pulse type 1 and 2 is shorter than the pulse period between pulse type 2 and 1 (Table 4). The spectral properties of each pulse type are the same (Table 4).

Calls of this species were previously described by Greenfield (1983), Walker and Greenfield (1983), Belwood and Morris (1987), Naskrecki (2000), Bush et al. (2009), and ter Hofstede et al. (2010).
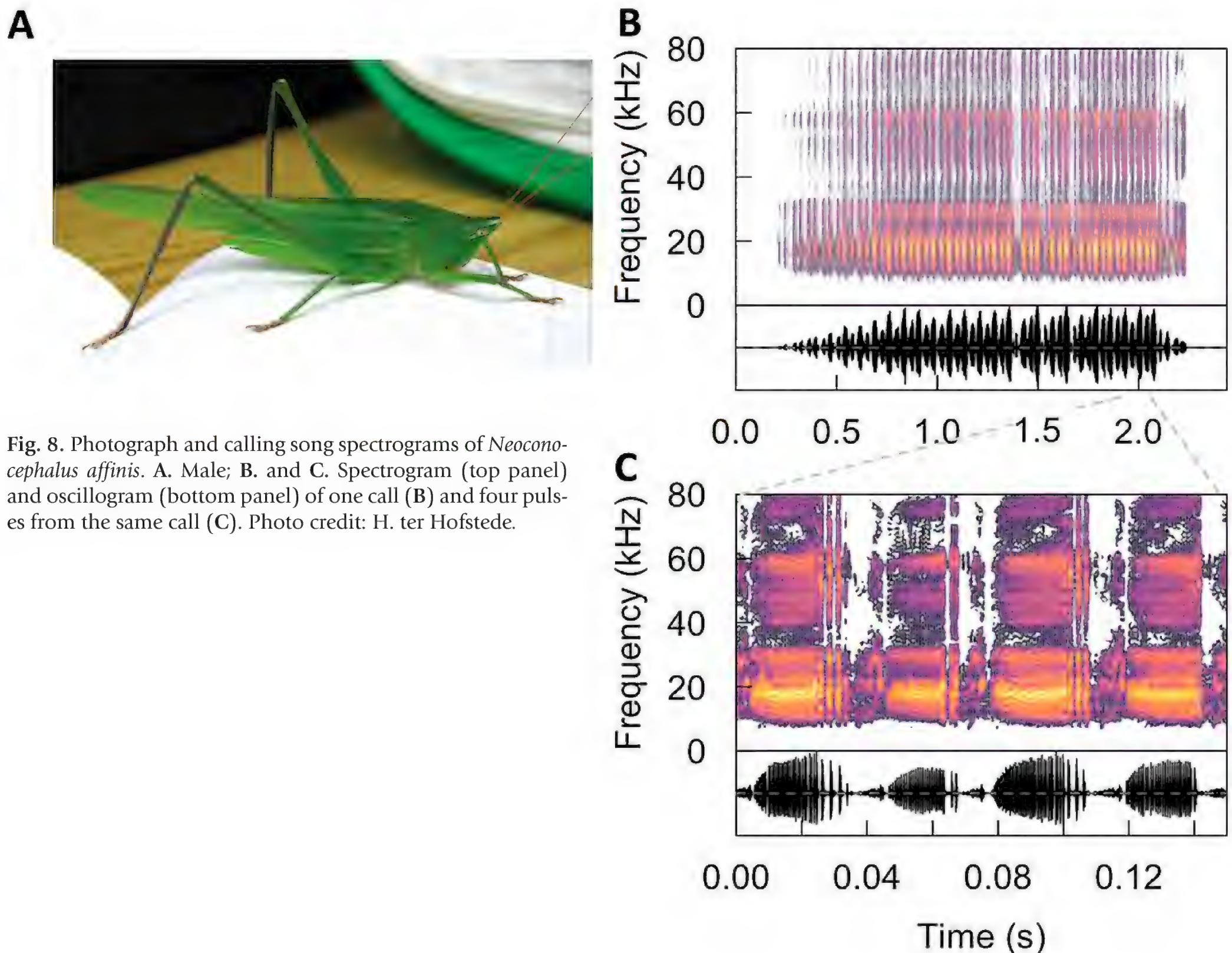

Fig. 8. Photograph and calling song spectrograms of *Neoconocephalus affinis*. **A.** Male; **B.** and **C.** Spectrogram (top panel) and oscillogram (bottom panel) of one call (**B**) and four pulses from the same call (**C**). Photo credit: H. ter Hofstede.

Table 4. Call pulse parameters of *Neoconocephalus affinis* (5 individuals, 25 calls; mean ± SD); n = number of pulses measured.

Pulse Type (n)	Pulse Duration (ms)	Pulse Period (ms)	Peak Frequency (kHz)	Low Frequency (kHz)	High Frequency (kHz)	Bandwidth (kHz)
1 (125)	20.7 ± 2.0	29.7 ± 2.5	14.6 ± 2.0	9.6 ± 0.4	29.3 ± 4.8	19.8 ± 4.5
2 (125)	29.0 ± 2.8	42.2 ± 3.4	14.6 ± 2.1	9.6 ± 0.4	27.0 ± 3.5	17.3 ± 3.3

Subria sylvestris **Naskrecki & Morris, 2000**
Fig. 9 [MNHN-SO-2019-1814, -1815, -1816]

Subria sylvestris is a small to mid-sized (0.55 ± 0.09 g, n = 11) katydid with both green and brown morphs, slightly translucent exoskeleton, and black markings on the posterior edge of the pronotum (Fig. 9A, B). This species is known from Costa Rica, Panama, and Colombia (Cigliano et al. 2020).

The call consists of two pulses with a very consistent mean call duration of 125 ms (Table 1; Fig. 9C, D). Calls can be produced singly or repeated at an interval of 1–3 s for long periods of time.

The peak frequency of the entire call is ~40 kHz with a -20 dB range spanning ~24–50 kHz, giving a bandwidth of ~26 kHz (Table 1). There is also significant energy at lower frequencies in the range of 20–25 kHz (Fig. 9D).

The pulses are often equal in amplitude and individual tooth strikes are visible on the oscillogram (Fig. 9D). The first pulse is usually longer than the second pulse (Table 5). The spectral properties of each pulse type are the same (Table 5).

Calls of this species were previously described by Naskrecki (2000), but they were recorded at a lower sampling rate that did not capture the higher frequencies described here.
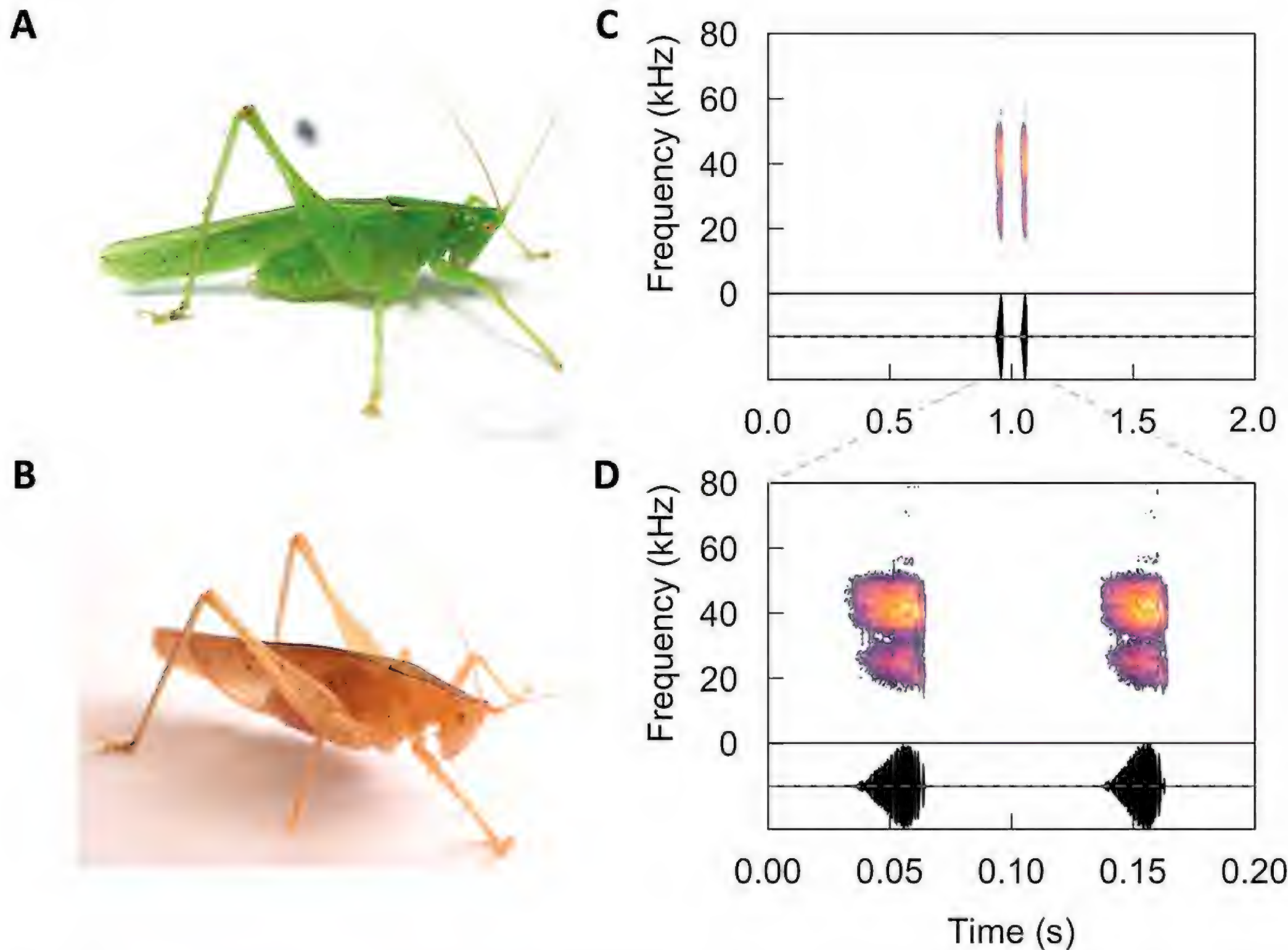

Fig. 9. Photographs and calling song spectrograms of *Subria sylvestris*. **A.** Male, green morph (photo credit: H. ter Hofstede); **B.** Female, brown morph (photo credit: T. Robillard); **C.** and **D.** Spectrogram (top panel) and oscillogram (bottom panel) of one call at different time scales.

Table 5. Call pulse parameters of *Subria sylvestris* (3 individuals, 37 calls; mean ± SD); n = number of pulses measured.

Pulse number (n)	Pulse Duration (ms)	Pulse Period (ms)	Peak Frequency (kHz)	Low Frequency (kHz)	High Frequency (kHz)	Bandwidth (kHz)
1 (37)	32.2 ± 1.7		38.9 ± 1.7	24.2 ± 5.4	49.1 ± 0.9	24.9 ± 6.1
2 (37)	26.6 ± 1.5	98.4 ± 1.3	38.6 ± 1.9	24.2 ± 6.8	49.2 ± 1.0	25.0 ± 7.7

Vestria punctata (Redtenbacher, 1891)
Fig. 10 [MNHN-SO-2019-1820, -1821, -1822]

Vestria punctata is a mid-sized (0.66 g, n = 1), green katydid with very distinctive markings (Fig. 10A, B). The facial markings are particularly striking, with brownish-yellow mouthparts, a band of dark green across the middle of the face, and white circular patches across the top. There are two white spots on the posterior edge of the pronotum and the abdomen is green on the dorsal surface, pale yellowish-green on the ventral surface, and has black spots on the sides. This species was redescribed by Naskrecki (2000), who mentioned several undescribed species of *Vestria* from Central America and the need for a critical taxonomic revision of the genus. This species is known from Costa Rica, Panama, Colombia, and Peru (Cigliano et al. 2020).

The call consists of two main pulses with what appear to be relatively high amplitude wing-opening sounds before each pulse (Fig. 10C, D). The first wing-opening sound is long and can be greater in amplitude than the first pulse, whereas the second wing-opening sound is very short. The total call duration is ~30 ms not including the first wing-opening sound (Table 1) and ~47 ms with the wing-opening sound. The peak frequency of the entire call is 30 kHz with a -20 dB range spanning 24–37 kHz, giving a bandwidth of 13 kHz (Table 1).

The first pulse is much shorter and lower in amplitude than the second pulse (Table 6; Fig. 10D). The spectral properties of each pulse are the same (Table 6). Individual tooth strikes are visible on the oscillogram for pulse 1 and 2, but not for the presumed wing-opening sounds (Fig. 10D).

Calls of this species were previously described by Naskrecki (2000), but they were recorded at a lower sampling rate that did not capture the higher frequencies described here.
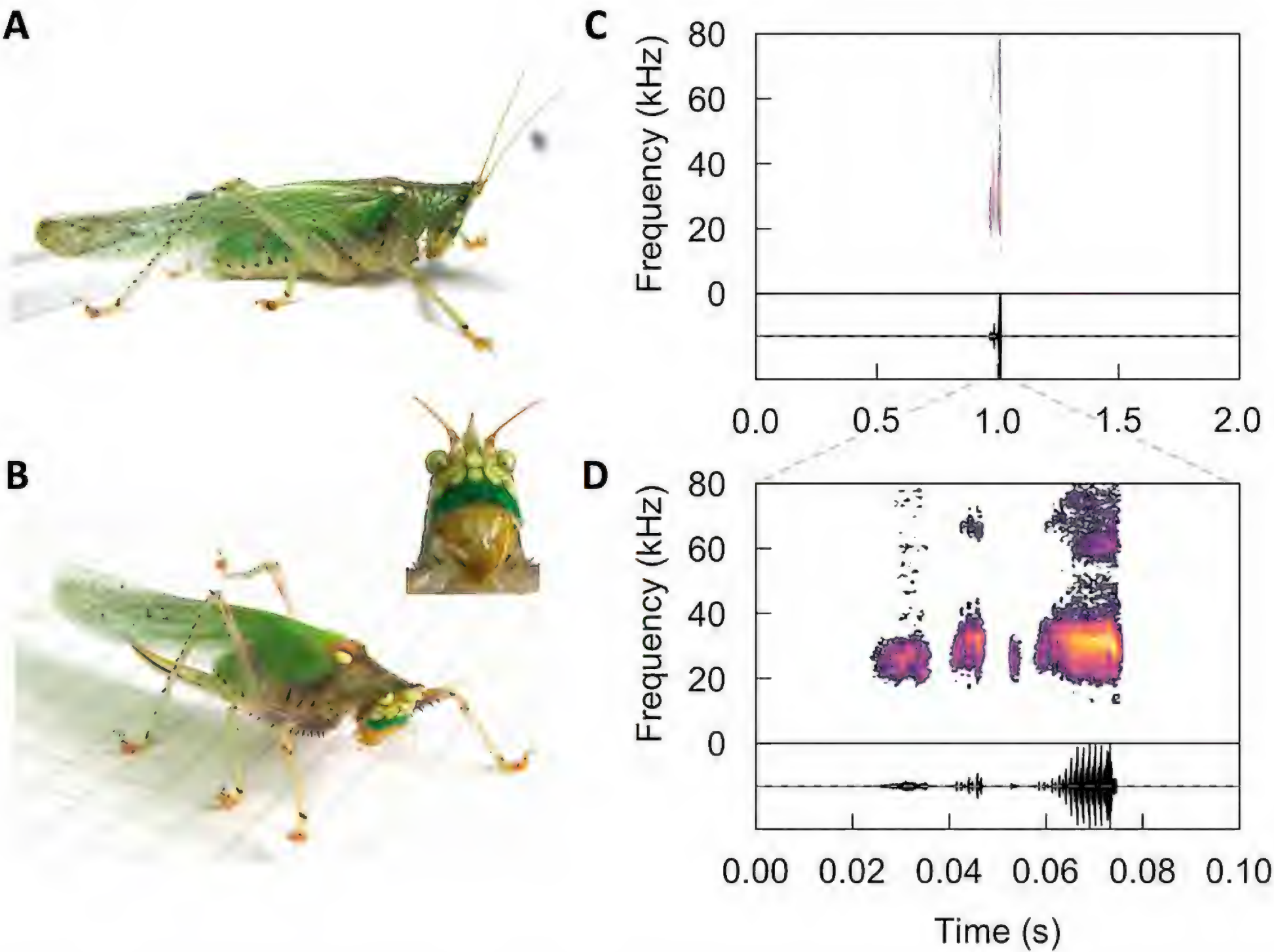

Fig. 10. Photographs and calling song spectrograms of *Vestria punctata*. **A.** Male; **B.** Female; inset: close-up of face; **C.** and **D.** Spectrogram (top panel) and oscillogram (bottom panel) of one call at different time scales. Photo credit: H. ter Hofstede.

Table 6. Call pulse parameters of *Vestria punctata* (3 individuals, 23 calls; mean ± SD); WO = long wing-opening sound at start of each call; n = number of pulses measured.

Pulse Number (n)	Pulse Duration (ms)	Pulse Period (ms)	Peak Frequency (kHz)	Low Frequency (kHz)	High Frequency (kHz)	Bandwidth (kHz)
WO (23)	11.0 ± 0.5		26.8 ± 2.6	21.4 ± 2.5	36.6 ± 3.6	15.1 ± 1.7
1 (23)	7.3 ± 0.4	15.6 ± 3.5	30.3 ± 1.5	23.7 ± 1.7	37.2 ± 1.6	13.5 ± 2.0
2 (22)	14.0 ± 2.2	18.6 ± 1.3	29.6 ± 1.3	24.7 ± 2.2	36.9 ± 1.9	12.2 ± 3.3

Phaneropterinae

Aegimia elongata Rehn, 1903
Fig. 11 [MNHN-SO-2019-212, -213, -214]

Aegimia elongata is a mid-sized (no weight data available), leaf-mimicking, green katydid with rounded tegmina, an elongated horn-like projection on the top of the head, and hind legs that are laterally flattened (Fig. 11A). This species is distinguished from *Aegemia maculifolia* by having a mainly green horn and legs (i.e., no completely brown leg segments). This species was redescribed by Dias et al. (2012). This species is known from Costa Rica, Panama, and Colombia (Nickle 1992, Cigliano et al. 2020).

Two call types can be produced by the same individual (two of the three recorded individuals produced both call types). There was no clear pattern for when the two call types would be produced; it appeared somewhat random whether the individual would produce call type 1 or 2. The spectral properties of the two call types are the same, with a peak frequency of ~10 kHz and a -20 dB range spanning ~7–20 kHz, giving a bandwidth of ~13 kHz (Table 1; Fig. 11B–E). The temporal properties of the two call types differ. Call type one starts with a long, low amplitude pulse followed by ~20 ms of silence, then a second higher amplitude, medium duration pulse followed by ~100 ms of silence, and ends with 1–3 very short pulses (Table 7; Fig. 11B, C). Individual tooth strikes are visible on the oscillogram for pulse one. Total pulses per call range from 3–5 with a mean call duration of ~200 ms (Table 1).

Call type two starts with a long, low amplitude pulse, followed after ~400 ms of silence by a series of 5–9 very short pulses that increase in amplitude (Table 8; Fig. 11D, E). The short pulses are repeated at regular intervals (Table 8). Total pulses per call range from 6–10, with a mean call duration of ~740 ms (Table 1). There are also very low amplitude pulses produced between the short pulses that are not characterized in detail here. These low amplitude pulses are irregular in duration and amplitude with tooth strikes visible on the oscillogram but have similar spectral properties to the other described pulses (Fig. 11D, E).

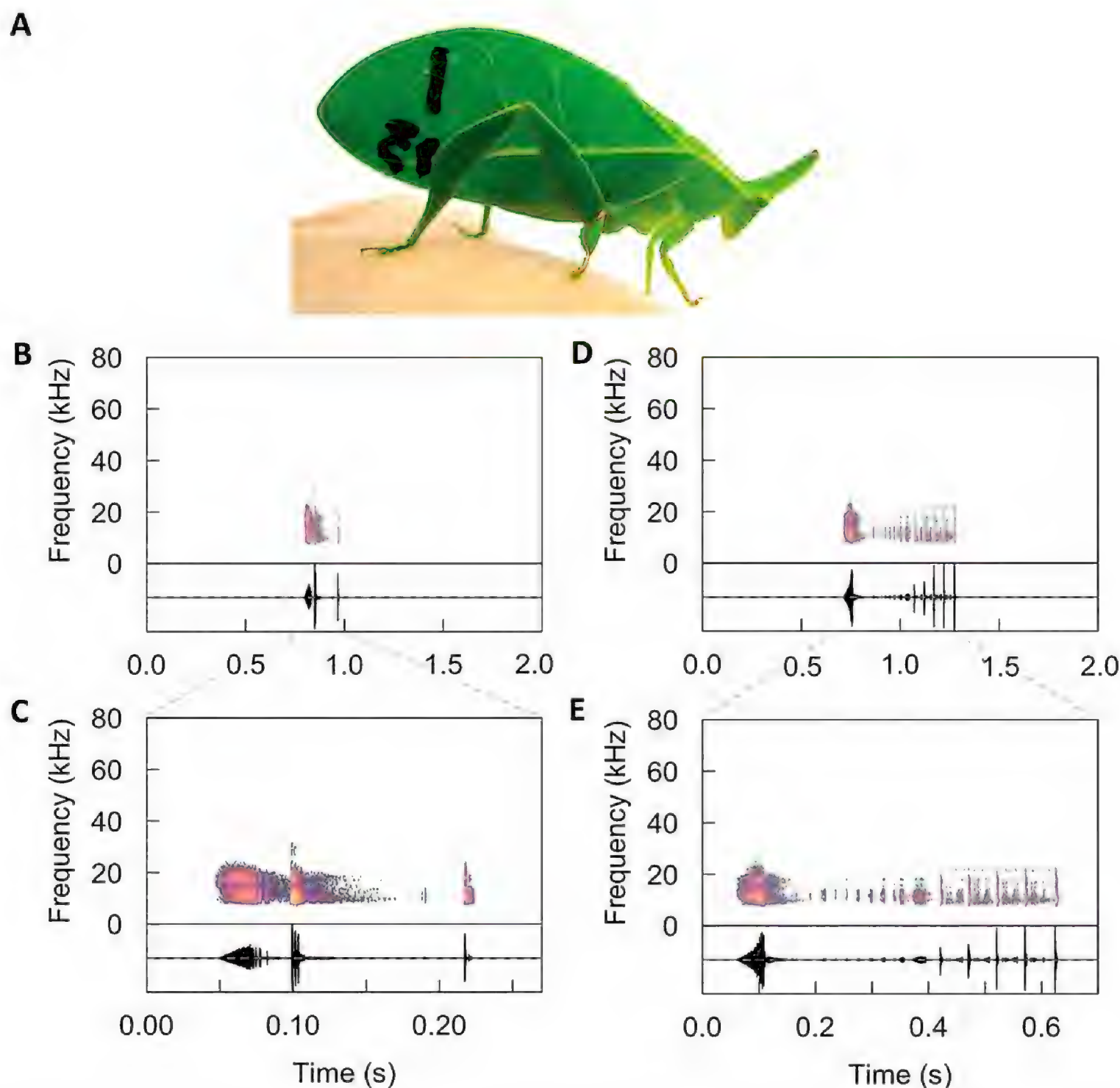This appears to be the first description of the call of this species.

Fig. 11. Photograph and calling song spectrograms of *Aegimia elongata*. **A.** Male with identification number written in ink; **B.** and **C.** Spectrogram (top panel) and oscillogram (bottom panel) of call type 1 at different time scales; **D.** and **E.** Spectrogram (top panel) and oscillogram (bottom panel) of call type 2 at different time scales. Photo credit: H. ter Hofstede.

Table 7. Call pulse parameters of *Aegimia elongata* call type 1 (3 individuals, 36 calls; mean ± SD); n = number of pulses measured.

Pulse Number (n)	Pulse Duration (ms)	Pulse Period (ms)	Peak Frequency (kHz)	Low Frequency (kHz)	High Frequency (kHz)	Bandwidth (kHz)
1 (36)	35.4 ± 5.4		11.9 ± 0.9	7.7 ± 0.3	20.4 ± 0.7	12.7 ± 0.8
2 (36)	8.0 ± 0.4	57.6 ± 6.0	9.8 ± 0.2	7.7 ± 0.2	19.8 ± 0.3	12.2 ± 0.5
3 (36)	3.8 ± 1.3	116.9 ± 3.0	10.6 ± 0.7	7.8 ± 0.4	16.0 ± 1.9	8.2 ± 1.5
4 (13)	4.9 ± 1.2	50.0 ± 5.7	10.4 ± 0.6	7.7 ± 0.6	16.8 ± 0.8	9.0 ± 0.2

Table 8. Call pulse parameters of *Aegimia elongata* call type 2 (2 individuals, 7 calls; mean ± SD); n = number of pulses measured. Only one individual produced calls with more than 6 pulses; thus, there is no SD for pulses 7–9.

Pulse Number (n)	Pulse Duration (ms)	Pulse Period (ms)	Peak Frequency (kHz)	Low Frequency (kHz)	High Frequency (kHz)	Bandwidth (kHz)
1 (7)	55.4 ± 6.9		10.2 ± 0.1	7.6 ± 0.5	20.1 ± 0.5	12.5 ± 1.0
2 (7)	3.1 ± 0.0	458.4 ± 139.6	10.0 ± 0.2	7.7 ± 0.5	19.0 ± 1.4	11.3 ± 1.9
3 (7)	3.1 ± 1.2	51.5 ± 3.3	10.0 ± 0.2	7.7 ± 0.5	19.2 ± 0.4	11.5 ± 0.9
4 (7)	4.2 ± 0.1	50.7 ± 1.3	10.0 ± 0.4	7.7 ± 0.5	19.3 ± 0.4	11.6 ± 0.2
5 (7)	5.2 ± 0.5	51.9 ± 1.9	10.1 ± 0.1	7.9 ± 0.2	16.8 ± 3.1	8.9 ± 2.9
6 (7)	5.2 ± 0.3	54.4 ± 1.9	10.2 ± 0.1	8.1 ± 0.2	18.9 ± 0.1	10.8 ± 0.1
7 (6)	5.5	57.2	10.0	8.0	19.0	11.0
8 (6)	6.0	61.2	10.0	7.8	19.2	11.4
9 (1)	1.9	95.9	9.7	7.8	19.0	11.2

Aegimia maculifolia Dias, Rafael, & Naskrecki, 2012
Fig. 12 [MNHN-SO-2019-215, -216, -217, -218, -219]

Aegimia maculifolia is a mid-size (0.63 ± 0.1 g, n = 16), leaf-mimicking, green katydid with rounded tegmina, an elongated horn-like projection on the top of the head, and hind legs that are laterally flattened (Fig. 12A, B). This species is distinguished from *Aegemia elongata* by having a completely brown mid-tibia and a brown tip to the horn. This species is known from Costa Rica, Panama, and Colombia (Cigliano et al. 2020).

The call consists of a series of 10–23 pulses (mean: 16) produced in groups (Fig. 12C, D), with a total call duration that is highly variable, ranging from 630–2,440 ms and a mean of ~1,400 ms (Table 1). The peak frequency of the call is ~17 kHz, with a -20 dB range spanning ~10–23 kHz, giving a bandwidth of ~13 kHz (Table 1). Pulses increase in amplitude across the call.

The pulses are similar in spectral properties (Table 9), with individual tooth strikes visible on the oscillogram and the peak frequency of the tooth strikes decreasing from ~19 to 13 kHz over

each pulse (Fig. 12D). The call usually starts with pulses being produced in groups of four (pulse group type 1), then one or two groups of three pulses (pulse group type 2), and ending with pulses grouped in pairs (pulse group type 3; Table 9). The first pulse of each pulse group is longer than the other pulses (Table 9) and has 2–3 distinct gaps in the tooth strike pattern (Fig. 12D, first pulse), whereas the other pulses in a group are shorter and tooth strikes are evenly spaced (Fig. 12D, second pulse). The most common call has 15 pulses arranged as two groups of four pulses, followed by one group of three pulses, followed by two pairs of pulses (Table 9), however many variations are produced by the same individual, including calls that lacked the three pulse group, have two three–pulse groups, or have 1–3 pairs of pulses at the end. The call in Fig. 11 provides an example of a particularly long call with three groups of four, two groups of three, and two groups of two pulses. Pulse durations range from 14–75 ms and pulse periods range from 50–230 ms, with means that vary depending on pulse group and pulse number within the group (Table 9).

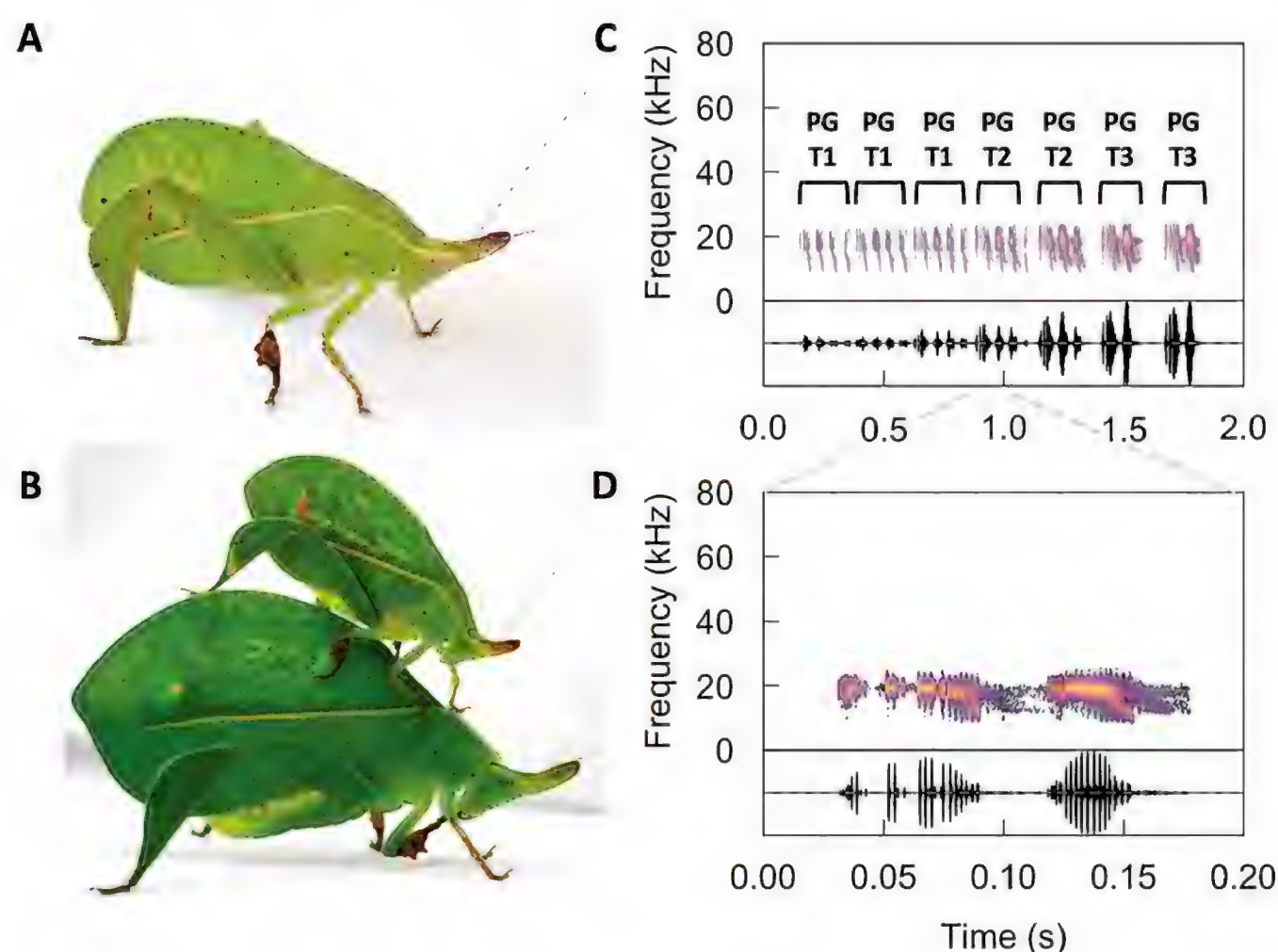This appears to be the first description of the call of this species.

Fig. 12. Photographs and calling song spectrograms of *Aegimia maculifolia*. **A.** Male (photo credit: T. Robillard); **B.** Male on female (photo credit: C. Kernan); **C.** and **D.** Spectrogram (top panel) and oscillogram (bottom panel) of one call (**C**) and two pulses from the same call (**D**). PGT# refers to pulse group type (see Table 9).

Table 9. Call pulse parameters of *Aegimia maculifolia* (5 individuals, 52 calls; mean ± SD); n = number of pulses measured. Values are given for the most common call type (pulses grouped as 4, 4, 3, 2, 2).

Pulse Group Type	Pulse Number (n)	Pulse Duration (ms)	Pulse Period (ms)	Peak Frequency (kHz)	Low Frequency (kHz)	High Frequency (kHz)	Bandwidth (kHz)
1	1 (52)	42.7 ± 3.0		16.1 ± 1.0	12.0 ± 0.4	21.6 ± 0.2	9.7 ± 0.4
1	2 (52)	35.8 ± 4.0	67.8 ± 3.5	16.4 ± 0.9	11.1 ± 0.5	21.9 ± 0.5	10.8 ± 0.9
1	3 (52)	32.9 ± 2.0	61.0 ± 6.9	14.9 ± 0.7	9.5 ± 0.4	20.9 ± 0.8	11.4 ± 1.0
1	4 (48)	26.7 ± 4.0	60.7 ± 2.2	13.8 ± 0.9	9.0 ± 0.6	20.1 ± 1.3	11.0 ± 1.1
1	5 (44)	58.0 ± 4.5	74.3 ± 9.7	16.4 ± 1.2	12.3 ± 0.6	22.1 ± 0.4	9.9 ± 0.7
1	6 (44)	35.9 ± 2.8	83.5 ± 6.6	16.8 ± 0.7	11.3 ± 1.2	22.0 ± 0.5	10.7 ± 1.7
1	7 (44)	33.3 ± 2.2	59.9 ± 5.6	15.6 ± 1.1	9.7 ± 0.5	21.0 ± 0.7	11.3 ± 0.9
1	8 (44)	25.1 ± 1.6	62.3 ± 2.1	13.9 ± 0.4	9.3 ± 0.3	20.1 ± 1.4	10.8 ± 1.4
2	9 (49)	63.0 ± 5.1	75.8 ± 3.1	17.4 ± 1.7	12.1 ± 1.2	22.2 ± 0.3	10.1 ± 1.4
2	10 (49)	35.2 ± 2.5	89.2 ± 8.4	18.2 ± 0.7	12.3 ± 0.9	22.1 ± 0.4	9.8 ± 1.1
2	11 (49)	32.4 ± 3.3	61.3 ± 2.7	15.7 ± 1.3	9.9 ± 0.5	21.4 ± 0.4	11.5 ± 0.6
3	12 (52)	65.4 ± 5.1	131.9 ± 8.6	17.4 ± 1.7	11.9 ± 1.3	22.2 ± 0.4	10.4 ± 1.6
3	13 (52)	37.2 ± 2.4	92.9 ± 7.5	18.2 ± 0.7	12.5 ± 1.0	22.1 ± 0.5	9.6 ± 1.3
3	14 (50)	65.5 ± 6.3	189.2 ± 11.2	17.5 ± 1.0	12.0 ± 1.0	22.1 ± 0.4	10.1 ± 1.3
3	15 (50)	34.3 ± 3.7	95.2 ± 8.6	17.5 ± 1.0	12.4 ± 1.0	22.0 ± 0.4	9.6 ± 1.2

Anapolisia colossea (Brunner von Wattenwyl, 1878)
Fig. 13 [MNHN-SO-2019-223, -224, -225, -226, -227, -228, -229, -230, -231]

Anapolisia colossea is a mid-size (0.91 ± 0.08 g, n = 112), green katydid with yellowish mouthparts and vertical bands on the broad wings that alternate between dark green and translucent with green specks (Fig. 13A, B). This species is known from Panama and Colombia (Nickle 1992, Cigliano et al. 2020).

The call consists of a series of 3–10 (mean: 5.6) short, broadband pulses (Fig. 13C, D) with a total call duration that is highly variable, ranging from ~0.8–4.0 s and having a mean of 2 s (Table 1). The peak frequency of the entire call is ~20 kHz, with a -20 dB range spanning ~12–25 kHz, giving a bandwidth of ~13 kHz (Table 1). The amplitude of the pulses can vary across the call, but not in a consistent manner. Sometimes the pulses within a call are all equal in amplitude, and sometimes they increase or decrease in amplitude across the call.

The pulses in the call are all very similar in their temporal and spectral properties (Table 10), but with the first pulse being slightly longer in duration than the others. The pulse period, however, gradually increases across the call (Table 10).

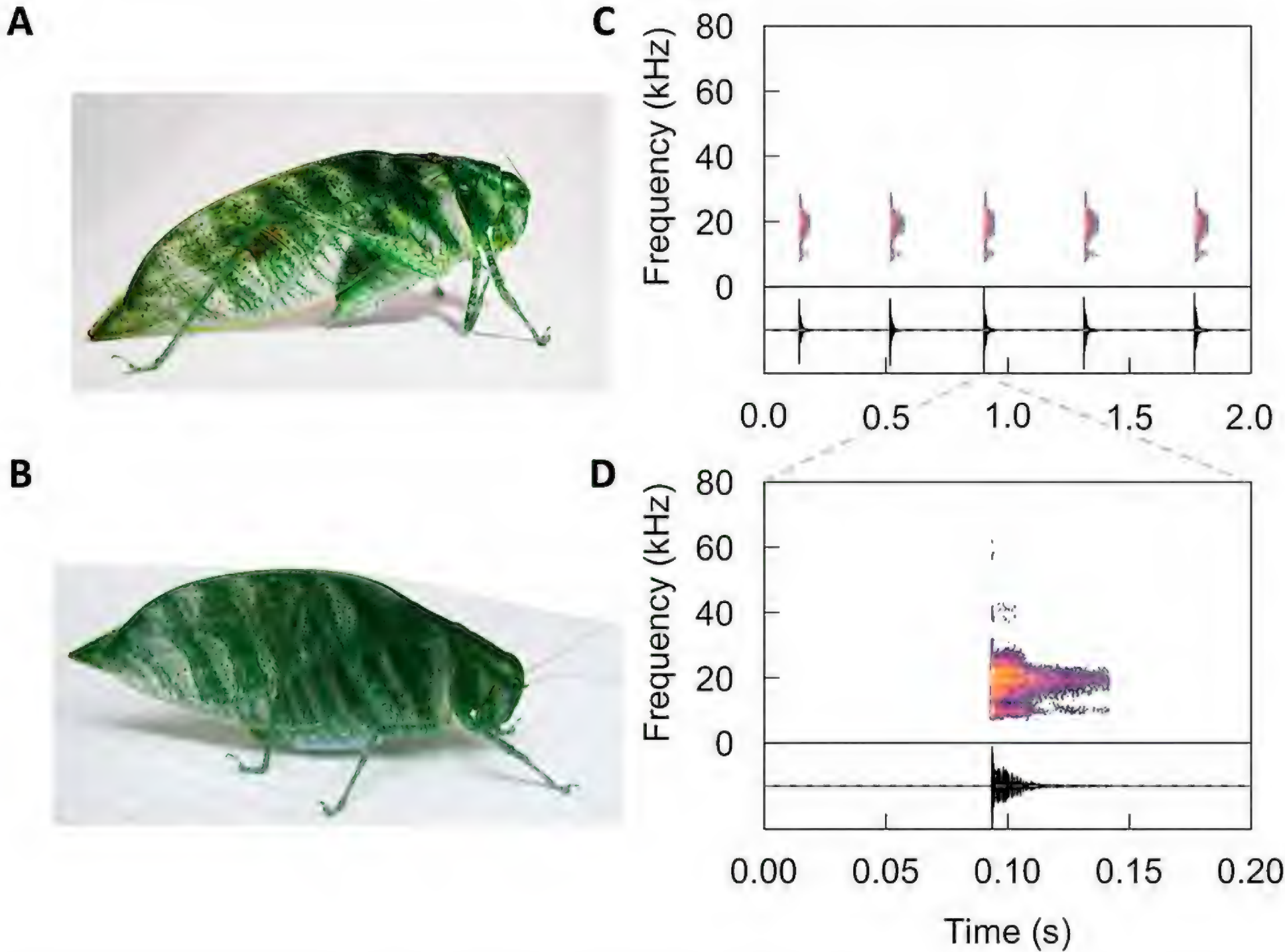The calls of this species were previously described by Falk et al. (2015) and Symes et al. (2016).

Fig. 13. Photographs and calling song spectrograms of *Anapolisia colossea*. **A.** Male (photo credit: C. Kernan); **B.** Female (photo credit: H. ter Hofstede); **C.** and **D.** Spectrogram (top panel) and oscillogram (bottom panel) of one call (**C**) and one pulse from the same call (**D**).

Table 10. Call pulse parameters of *Anapolisia colossea* (9 individuals, 116 calls; mean ± SD); n = number of pulses measured.

Pulse Number (n)	Pulse Duration (ms)	Pulse Period (ms)	Peak Frequency (kHz)	Low Frequency (kHz)	High Frequency (kHz)	Bandwidth (kHz)
1 (116)	13.4 ± 1.4		19.7 ± 0.7	9.6 ± 0.7	26.3 ± 1.0	16.7 ± 0.8
2 (116)	11.6 ± 1.4	376.0 ± 11.7	19.8 ± 0.6	9.8 ± 0.9	26.4 ± 1.0	16.6 ± 1.2
3 (116)	11.3 ± 1.5	394.0 ± 18.7	19.8 ± 0.7	9.7 ± 0.8	26.4 ± 1.1	16.7 ± 1.1
4 (112)	11.6 ± 1.5	423.5 ± 19.5	19.8 ± 0.6	9.6 ± 0.7	26.5 ± 1.0	16.9 ± 1.1
5 (84)	11.3 ± 1.9	435.7 ± 25.1	19.9 ± 0.5	9.8 ± 0.9	26.3 ± 1.0	16.6 ± 1.3
6 (59)	11.0 ± 2.1	460.9 ± 23.3	19.8 ± 0.5	9.6 ± 1.0	26.3 ± 1.1	16.6 ± 1.8
7 (35)	11.7 ± 2.1	516.1 ± 69.6	19.8 ± 1.2	9.8 ± 1.5	26.6 ± 1.3	16.7 ± 2.5
8 (10)	12.1 ± 1.1	465.9 ± 96.6	19.4 ± 0.7	9.8 ± 1.7	26.8 ± 1.4	17.0 ± 3.0
9 (3)	13.5 ± 1.1	519.2 ± 15.4	20.1 ± 0.5	9.2 ± 0.0	27.4 ± 0.5	18.2 ± 0.5

Anaulacomera furcata Brunner von Wattenwyl, 1878
Fig. 14 [MNHN-SO-2019-232, -233, -234]

Anaulacomera furcata is a very small (0.14 ± 0.04 g, n = 43), green katydid with narrow wings, a solid green face, three black spots on the posterior edge of the pronotum, light yellow stripes along the dorsal margins of the pronotum, and male cerci that are forked, having two branches at the end (Fig. 14A, B). This species is known from Costa Rica, Panama, and Colombia (Cigliano et al. 2020).

The call consists of two short pulses of equal amplitude produced ~20 ms apart (Table 11; Fig. 14C, D). The peak frequency of the entire call is ~29 kHz, with a -20 dB range spanning ~24–36 kHz, giving a bandwidth of ~12 kHz (Table 1). The two pulses have similar temporal and spectral properties (Table 11).

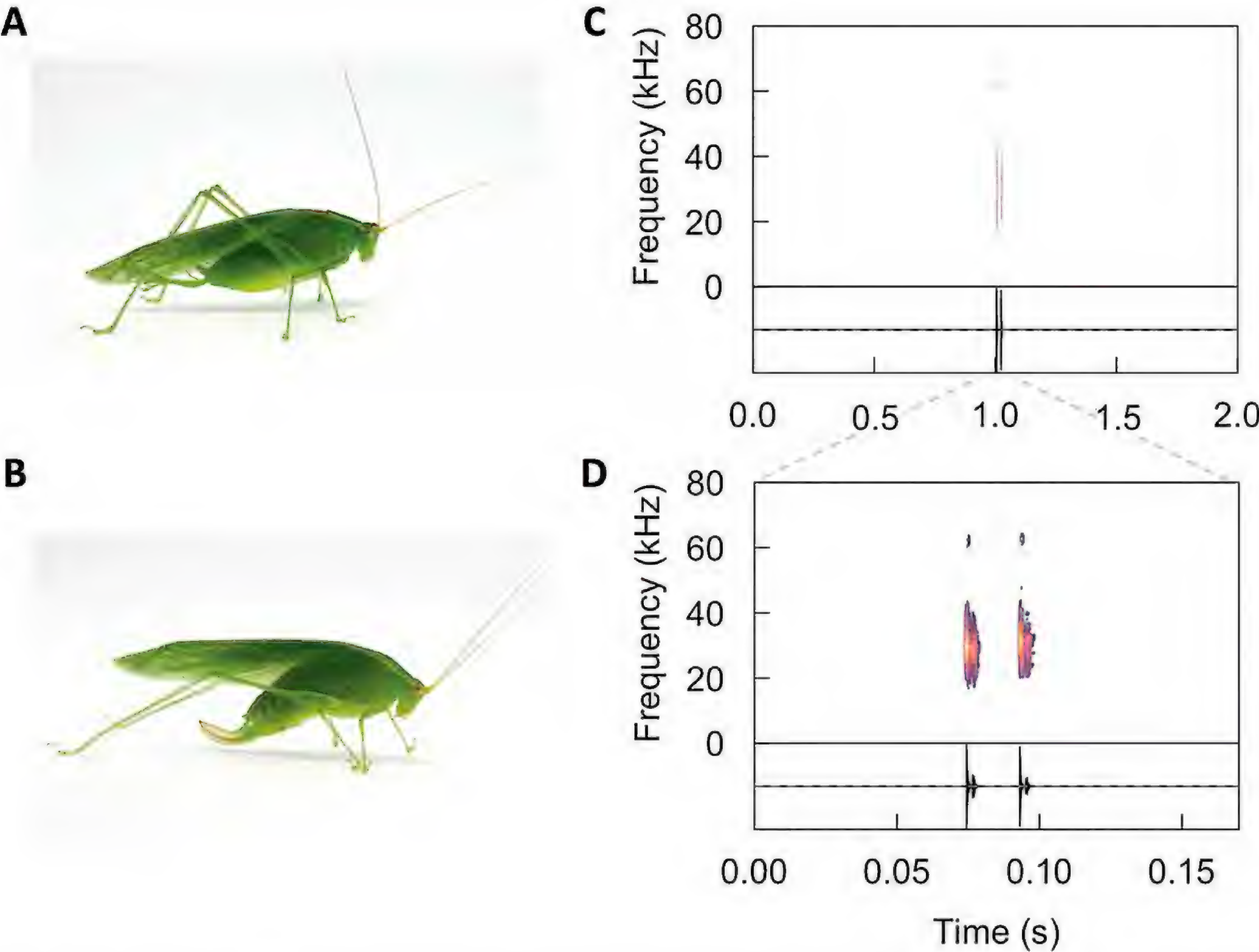This appears to be the first description of the call of this species.

Fig. 14. Photographs and calling song spectrograms of *Anaulacomera furcata*. **A.** Male; **B.** Female; **C.** and **D.** Spectrogram (top panel) and oscillogram (bottom panel) of one call at different time scales. Photo credit: C. Kernan.

Table 11. Call pulse parameters of *Anaulacomera furcata* (3 individuals, 53 calls; mean ± SD); n = number of pulses measured.

Pulse number (n)	Pulse Duration (ms)	Pulse Period (ms)	Peak Frequency (kHz)	Low Frequency (kHz)	High Frequency (kHz)	Bandwidth (kHz)
1 (53)	0.8 ± 0.1		29.2 ± 1.1	24.8 ± 1.1	35.0 ± 0.7	10.2 ± 1.3
2 (53)	0.9 ± 0.1	20.2 ± 1.5	29.8 ± 0.7	25.0 ± 0.7	35.8 ± 0.3	10.8 ± 0.7

Anaulacomera "goat"
Fig. 15

Anaulacomera "goat" is a very small (0.16 ± 0.02 g, n = 12), green katydid with narrow wings, a dark line through the eye, and a dark brown stridulatory area in males (Fig. 15A, B). We were not able to identify these individuals to species and provide the temporary species name "goat" due to the unique eye patterning. The calls recorded from these individuals are all the same and can be readily distinguished from the other species of *Anaulacomera* we collected in Panama.

The call consists of a single pulse with a duration ~2 ms (Table 1; Fig. 15C, D). The peak frequency of the call is ~27 kHz, with a -20 dB range spanning 23–33 kHz, giving a bandwidth of 10 kHz.
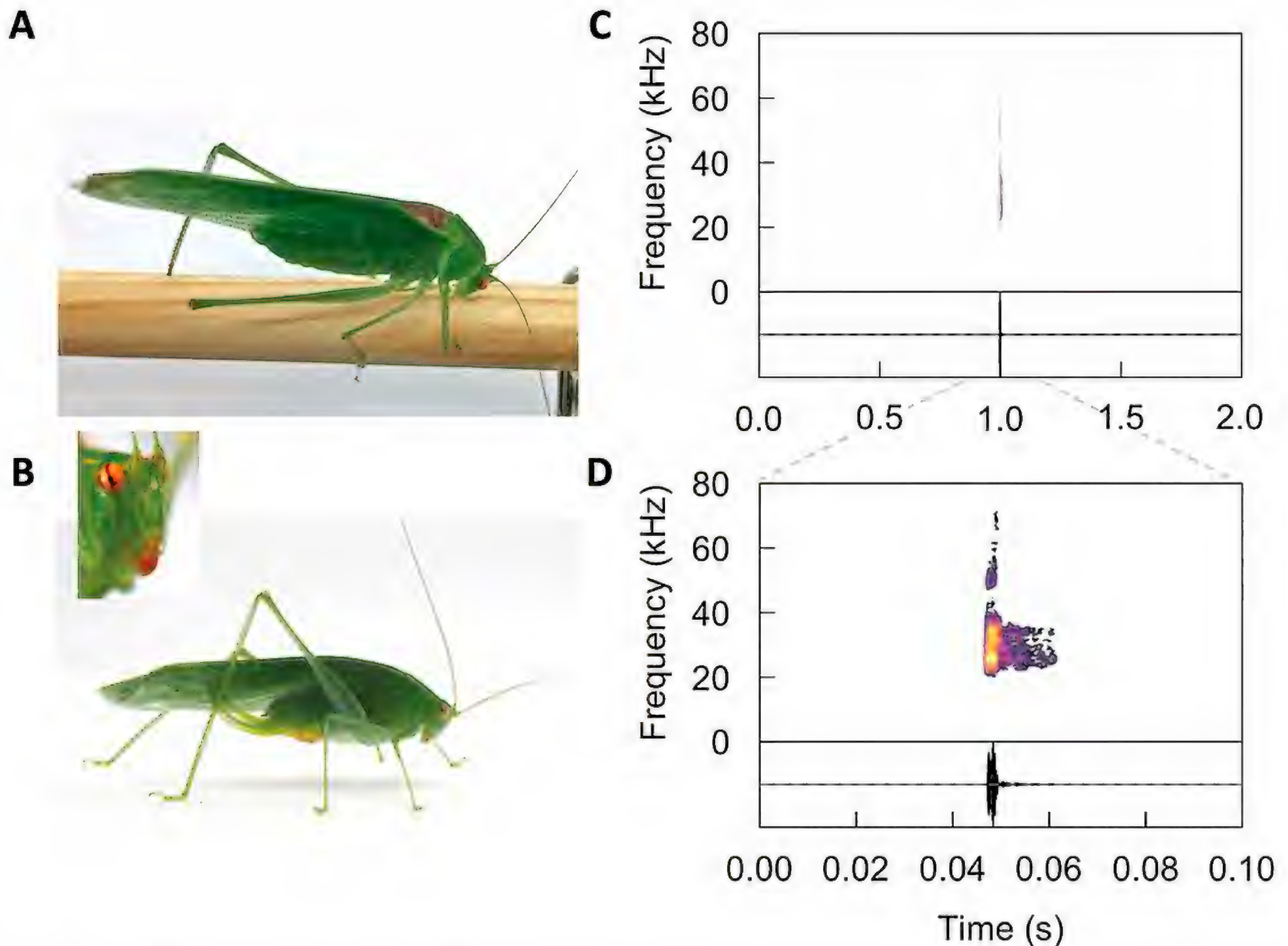

Fig. 15. Photographs and calling song spectrograms of *Anaulacomera* "goat". **A.** Male (photo credit: C. Wilson); **B.** Female (photo credit: C. Kernan). Inset shows dark line through eye; **C.** and **D.** Spectrogram (top panel) and oscillogram (bottom panel) of one call at different time scales.

Anaulacomera "**ricotta**"
Fig. 16

Anaulacomera "ricotta" is a very small (0.12 ± 0.02 g, n = 7), green katydid with narrow wings, a white and green mottled body, and male cerci that are forked, having two branches at the end, one of which ends in a spiral coil (Fig. 16A, B). We were not able to identify these individuals to species and provide the temporary species name "ricotta" due to the unique white mottling on the body.

The call consists of two short pulses of equal amplitude produced ~60 ms apart (Table 12; Fig. 16C, D). The peak frequency of the entire call is ~34 kHz, with a -20 dB range spanning ~29–39 kHz, giving a bandwidth of ~10 kHz (Table 1). The two pulses have similar temporal and spectral properties (Table 12).
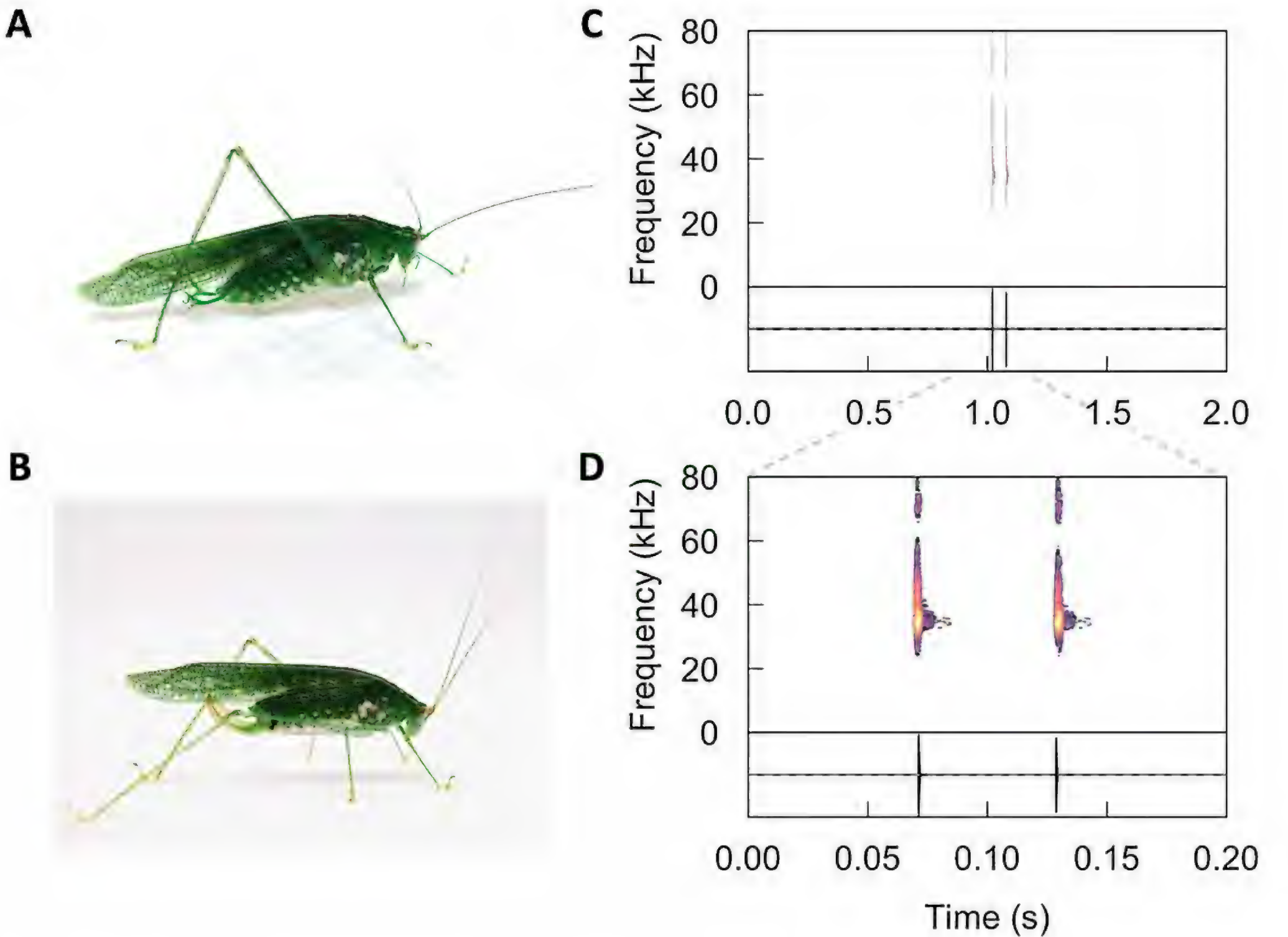

Fig. 16. Photographs and calling song spectrograms of *Anaulacomera* "ricotta". **A.** Male (photo credit: H. ter Hofstede); **B.** Female (photo credit: C. Kernan); **C.** and **D.** Spectrogram (top panel) and oscillogram (bottom panel) of one call at different time scales.

Table 12. Call pulse parameters of *Anaulacomera* "ricotta" (3 individuals, 16 calls; mean ± SD); n = number of pulses measured.

Pulse Number (n)	Pulse Duration (ms)	Pulse Period (ms)	Peak Frequency (kHz)	Low Frequency (kHz)	High Frequency (kHz)	Bandwidth (kHz)
1 (16)	1.0 ± 0.2		33.2 ± 2.5	29.5 ± 2.1	38.0 ± 0.2	8.4 ± 1.9
2 (16)	1.0 ± 0.2	58.0 ± 1.9	33.9 ± 1.5	30.1 ± 1.6	38.0 ± 0.1	7.9 ± 1.6

***Anaulacomera spatulata* Hebard, 1927**
Fig. 17 [MNHN-SO-2019-238, -239, -240]

Anaulacomera spatulata is a small (0.30 ± 0.08 g, n = 129), green katydid with very narrow wings. Males have a dark brown stridulatory area and spatulate cerci (Fig. 17A, B). This species is known from Panama, Colombia, and Suriname (Cigliano et al. 2020).

The call consists of two short pulses of equal amplitude produced ~40 ms apart (Table 13; Fig. 17C, D). The peak frequency of the entire call is ~25 kHz, with a -20 dB range spanning ~22–29 kHz, giving a bandwidth of ~7 kHz (Table 1). The two pulses have similar temporal and spectral properties (Table 13).

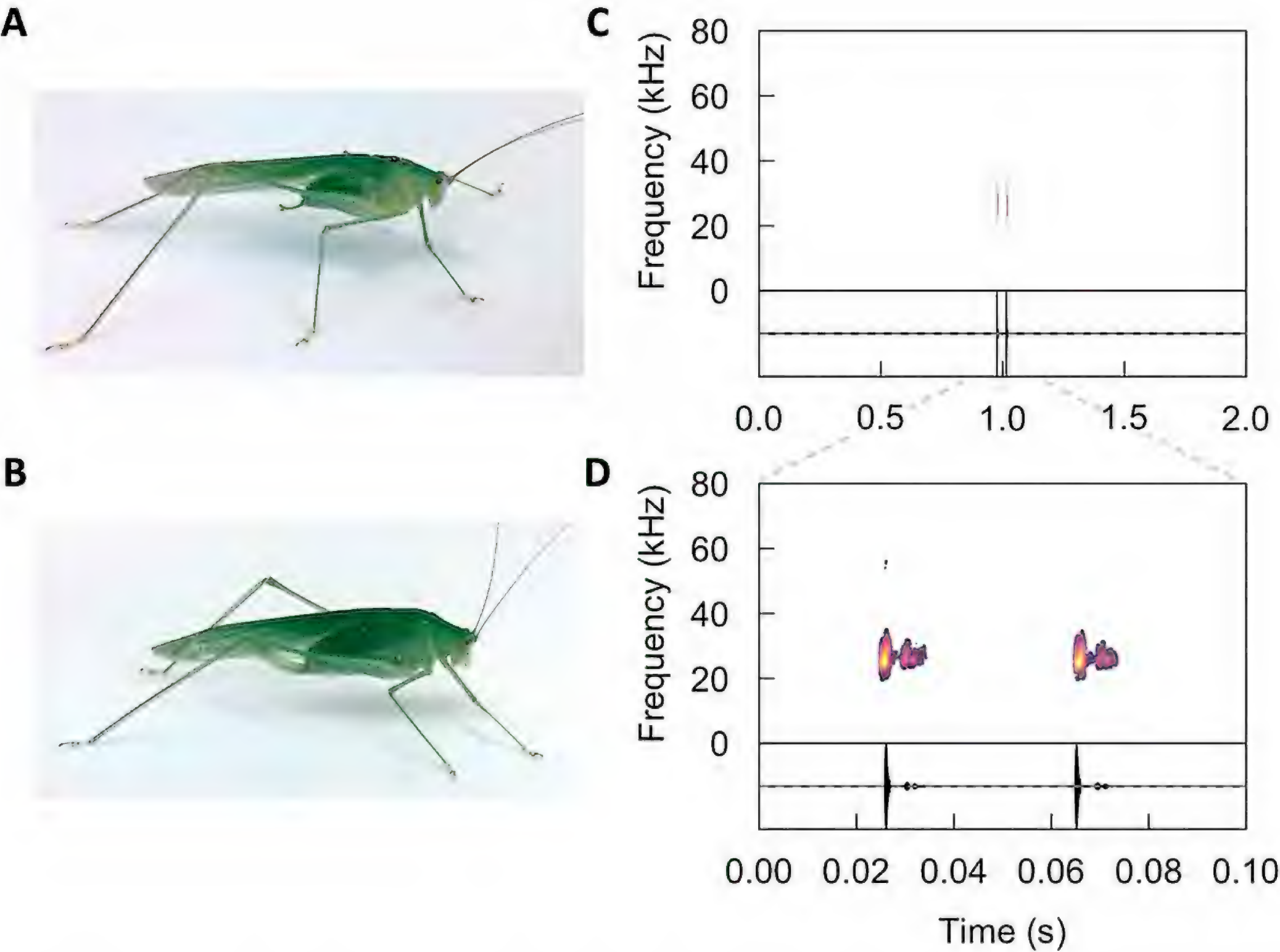This appears to be the first description of the call of this species.

Fig. 17. Photographs and calling song spectrograms of *Anaulacomera spatulata*. **A.** Male; **B.** Female; **C.** and **D.** Spectrogram (top panel) and oscillogram (bottom panel) of one call at different time scales. Photo credit: C. Wilson.

Table 13. Call pulse parameters of *Anaulacomera spatulata* (3 individuals, 59 calls; mean ± SD); n = number of pulses measured.

Pulse number (n)	Pulse Duration (ms)	Pulse Period (ms)	Peak Frequency (kHz)	Low Frequency (kHz)	High Frequency (kHz)	Bandwidth (kHz)
1 (59)	1.3 ± 0.2		24.6 ± 3.2	22.2 ± 3.3	29.3 ± 2.5	7.1 ± 1.3
2 (59)	1.4 ± 0.3	41.4 ± 2.3	24.3 ± 3.7	22.0 ± 3.3	29.3 ± 2.0	7.3 ± 1.4

Anaulacomera "wallace"
Fig. 18

Anaulacomera "wallace" is a very small (0.22 ± 0.05 g, n = 28), green katydid with narrow wings, a green and white mottled face, eyes that are half green and half white, and highly reduced cerci in males (Fig. 18A, B). We were not able to identify these individuals to species, and we provide the temporary species name "wallace."

The calls recorded from these individuals are all the same and can be readily distinguished from the other species of *Anaulacomera* that we collected in Panama.

The call consists of three short pulses of equal amplitude produced ~16 ms apart (Table 14; Fig. 18C, D). The peak frequency of the entire call is ~25 kHz, with a -20 dB range spanning ~20–31 kHz, giving a bandwidth of ~11 kHz (Table 1). The three pulses have similar temporal and spectral properties (Table 13).
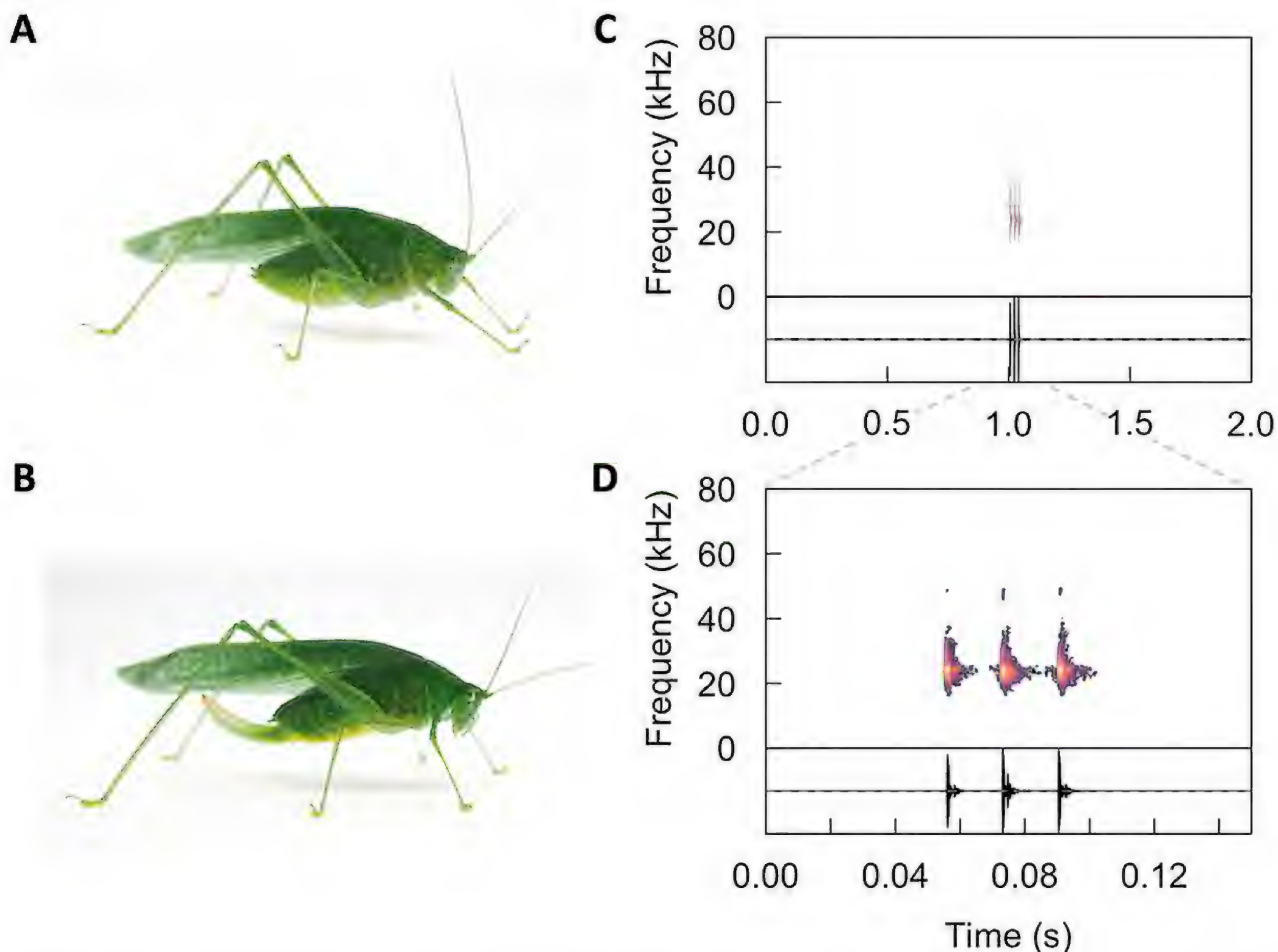

Fig. 18. Photographs and calling song spectrograms of *Anaulacomera* "wallace". **A.** Male; **B.** Female; **C.** and **D.** Spectrogram (top panel) and oscillogram (bottom panel) of one call at different time scales. Photo credit: C. Kernan.

Table 14. Call pulse parameters of *Anaulacomera* "wallace" (4 individuals, 19 calls; mean ± SD); n = number of pulses measured.

Pulse number (n)	Pulse Duration (ms)	Pulse Period (ms)	Peak Frequency (kHz)	Low Frequency (kHz)	High Frequency (kHz)	Bandwidth (kHz)
1 (19)	1.2 ± 0.2		25.3 ± 1.7	21.4 ± 0.7	29.1 ± 2.6	7.7 ± 3.1
2 (19)	1.0 ± 0.2	16.5 ± 0.7	25.0 ± 0.6	21.5 ± 1.3	29.7 ± 3.4	8.2 ± 4.3
3 (18)	0.9 ± 0.2	16.2 ± 1.1	25.1 ± 0.9	21.7 ± 1.2	29.9 ± 3.4	8.2 ± 4.2

Arota festae (Griffini, 1896)
Fig. 19 [MNHN-SO-2019-241, -246, -247, -248, -249, -250, -251, -252, -253, -254]

Arota festae is a mid-sized (0.98 ± 0.15 g, n = 34), light green katydid with broad, rounded tegmina that cover nearly all of the hindwings (<3 mm visible beyond the apex of the tegmina) (Fig. 19A, B). This species is known from Panama, Colombia, and Suriname (Cigliano et al. 2020).

The call consists of a series of 7–10 (mean: 8) short pulses (Fig. 19C, D) with a total call duration ranging from ~15–28 ms and having a mean of 21 ms (Table 1). The peak frequency of the entire call is ~13 kHz with a -20 dB frequency range spanning ~8–19 kHz, giving a bandwidth of ~11 kHz (Table 1). The amplitude of the pulses varies across the call. In most cases, the pulses increase in amplitude (Fig. 19D), but sometimes they increase and then decrease in amplitude.

Pulse durations are short and increase slightly in duration over the call, whereas pulse period stays constant across the call (Table 15). The peak frequency of each pulse increases across the call (Table 15). The low and high frequencies of each pulse also increase across the call, with bandwidths ranging from 5–9 kHz, depending on the pulse (Table 15).

The calls of this species were previously described by Symes et al. (2016).
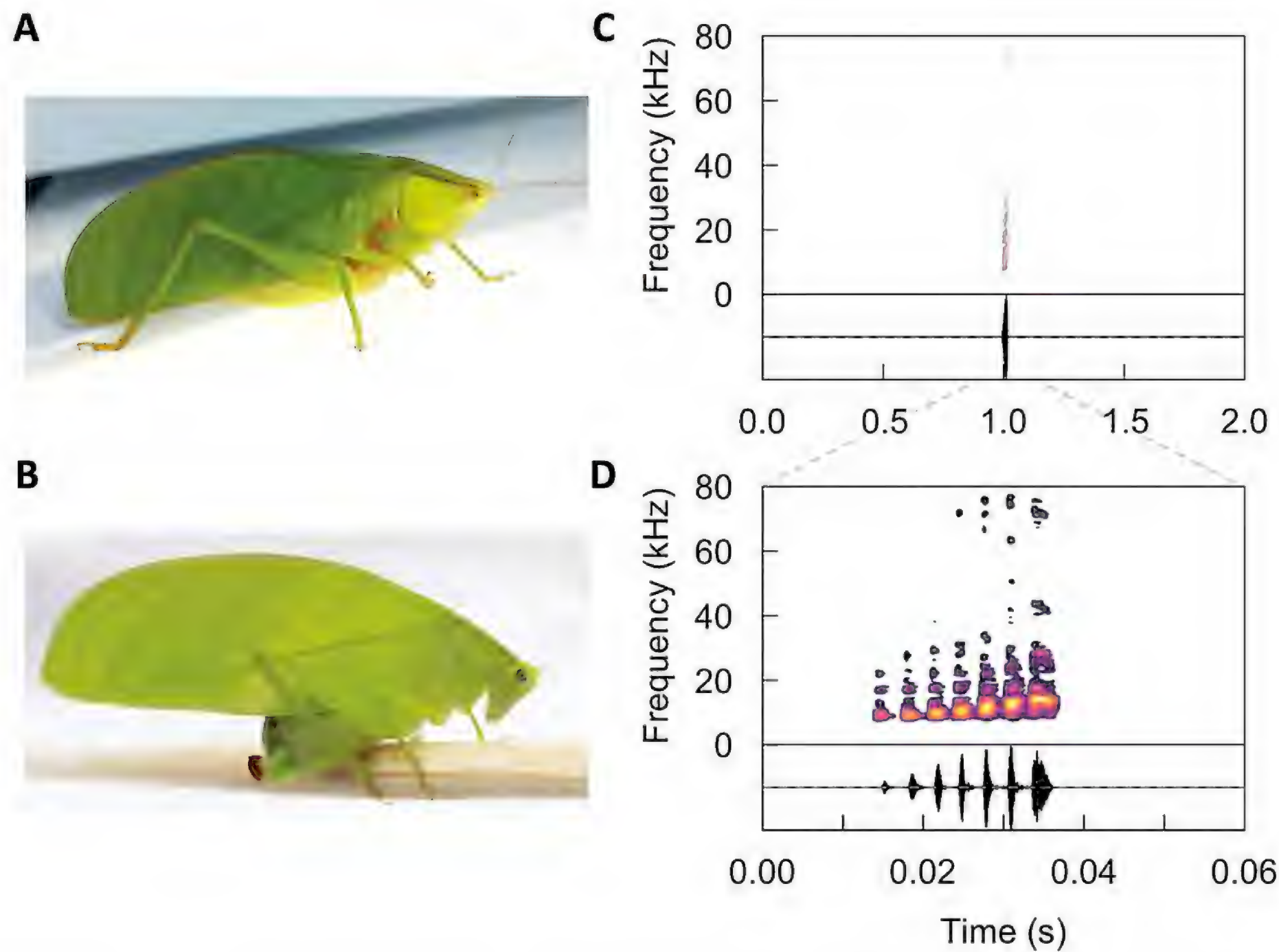

Fig. 19. Photographs and calling song spectrograms of *Arota festae*. **A.** Male; **B.** Female; **C.** and **D.** Spectrogram (top panel) and oscillogram (bottom panel) of one call at different time scales. Photo credit: C. Wilson.

Table 15. Call pulse parameters of *Arota festae* (10 individuals, 83 calls; mean ± SD); n = number of pulses measured.

Pulse Number (n)	Pulse Duration (ms)	Pulse Period (ms)	Peak Frequency (kHz)	Low Frequency (kHz)	High Frequency (kHz)	Bandwidth (kHz)
1 (83)	0.8 ± 0.2		8.7 ± 0.3	6.7 ± 0.6	15.8 ± 2.2	9.1 ± 2.3
2 (83)	1.0 ± 0.2	3.0 ± 0.5	8.8 ± 0.2	7.3 ± 0.4	14.3 ± 2.2	7.0 ± 2.4
3 (83)	1.0 ± 0.2	2.7 ± 0.4	9.2 ± 0.3	7.7 ± 0.2	13.2 ± 2.2	5.5 ± 2.3
4 (83)	1.0 ± 0.2	2.7 ± 0.4	9.7 ± 0.4	8.0 ± 0.3	13.7 ± 2.1	5.7 ± 2.0
5 (83)	1.0 ± 0.1	2.7 ± 0.5	10.6 ± 0.5	8.4 ± 0.3	15.0 ± 2.2	6.6 ± 2.1
6 (83)	0.9 ± 0.1	2.8 ± 0.4	11.9 ± 1.0	9.1 ± 0.6	17.1 ± 2.4	8.0 ± 2.4
7 (83)	1.2 ± 0.3	2.9 ± 0.3	13.5 ± 0.8	10.4 ± 1.3	17.9 ± 1.5	7.5 ± 2.0
8 (62)	1.3 ± 0.2	2.9 ± 0.3	14.4 ± 0.9	10.9 ± 1.0	19.3 ± 2.7	8.4 ± 2.5
9 (26)	1.4 ± 0.2	2.8 ± 0.5	14.3 ± 0.8	11.4 ± 0.4	18.1 ± 1.2	6.7 ± 1.0

Arota panamae **(Hebard, 1927)**
Fig. 20 [MNHN-SO-2019-255, -256, -288, -289, -290, -291, -292, -293, -294, -295]

Arota panamae is a mid-sized (0.57 ± 0.11 g, n = 68), light green katydid with broad wings and hindwings that extend >3 mm beyond the apex of the tegmina (Fig. 20A, B). This species is known from Panama and Colombia (Cigliano et al. 2020).

The call consists of a series of 3–6 (mean: 5) short pulses (Fig. 20C, D) with a total call duration ranging from ∼8–25 ms and having a mean of ∼15 ms (Table 1). The peak frequency of the entire call is ∼24 kHz with a -20 dB frequency range spanning ∼15–33 kHz, giving a bandwidth of ∼18 kHz (Table 1). The amplitude of the pulses varies across the call. The pulses either increase in amplitude or they increase and then decrease in amplitude across the call (Fig. 20D).

Pulse durations are short and increase over the call, whereas pulse period stays constant (Table 16). The peak frequency of each pulse increases across the call (Table 16). The low and high frequencies of each pulse also increase across the call, with bandwidths ranging from 10–20 kHz depending on the pulse (Table 16).

The calls of this species were previously described by Falk et al. (2015) and Symes et al. (2016).
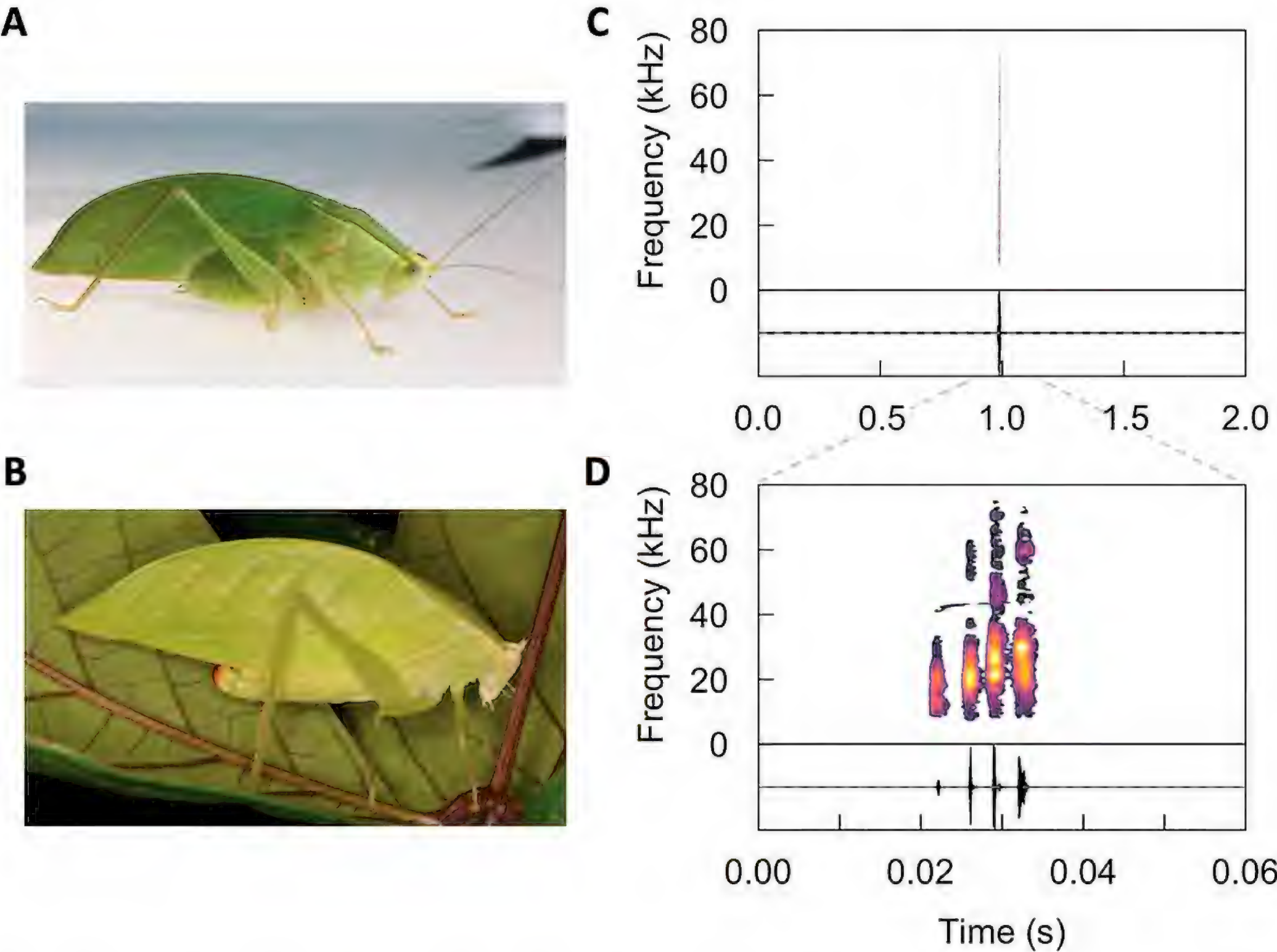

Fig. 20. Photographs and calling song spectrograms of *Arota panamae*. **A.** Male (photo credit: C. Wilson); **B.** Female (photo credit: M. Ayres); **C.** and **D.** Spectrogram (top panel) and oscillogram (bottom panel) of one call at different time scales.

Table 16. Call pulse parameters of *Arota panamae* (10 individuals, 156 calls; mean ± SD); n = number of pulses measured.

Pulse Number (n)	Pulse Duration (ms)	Pulse Period (ms)	Peak Frequency (kHz)	Low Frequency (kHz)	High Frequency (kHz)	Bandwidth (kHz)
1 (156)	0.4 ± 0.1		12.1 ± 1.4	7.5 ± 0.9	25.2 ± 4.1	17.8 ± 4.0
2 (156)	0.5 ± 0.1	3.3 ± 0.8	14.3 ± 2.5	9.7 ± 1.7	26.9 ± 3.3	17.1 ± 3.1
3 (156)	0.5 ± 0.1	3.6 ± 0.5	18.2 ± 3.0	13.2 ± 2.7	28.9 ± 3.5	15.7 ± 3.4
4 (151)	0.7 ± 0.2	3.6 ± 0.4	23.2 ± 3.2	16.3 ± 3.0	31.6 ± 2.5	15.3 ± 3.2
5 (118)	1.0 ± 0.3	3.6 ± 0.5	26.8 ± 1.7	20.2 ± 3.4	34.7 ± 3.5	14.4 ± 5.1
6 (48)	1.1 ± 0.2	3.3 ± 0.3	27.9 ± 1.0	23.0 ± 1.5	34.7 ± 3.6	11.7 ± 4.7

Ceraia mytra **Grant, 1964**
Fig. 21 [MNHN-SO-2019-302, -303, -304, -305, -306, -307, -308,
-309, -310]

Ceraia mytra is a large (1.30 ± 0.28 g, n = 31), green katydid with narrow wings, reddish cerci, and reddish-purple hindlegs (Fig. 21A, B). This species is known from Costa Rica, Panama, and Colombia (Cigliano et al. 2020).

The call consists of a series of 6–13 (mean: 10) short pulses (Fig. 21C, D) with a total call duration ranging from ~40–96 ms and having a mean of ~76 ms (Table 1). The peak frequency of the entire call is ~11 kHz with a -20 dB frequency range spanning ~7–20 kHz,

giving a bandwidth of ~13 kHz (Table 1). The amplitude of the pulses varies across the call. The pulses either increase in amplitude (Fig. 21D) or they increase and then decrease in amplitude across the call.

The pulses in the call are all very similar in their temporal and spectral properties (Table 17). Pulses sometimes have silent gaps within them, making it look like there are two shorter pulses separated by a very short silent period (e.g., pulse six in Fig. 21D). The peak frequency of each pulse decreases slightly across the call (Table 17). The low and high frequencies of each pulse also decrease slightly across the call (Table 17).

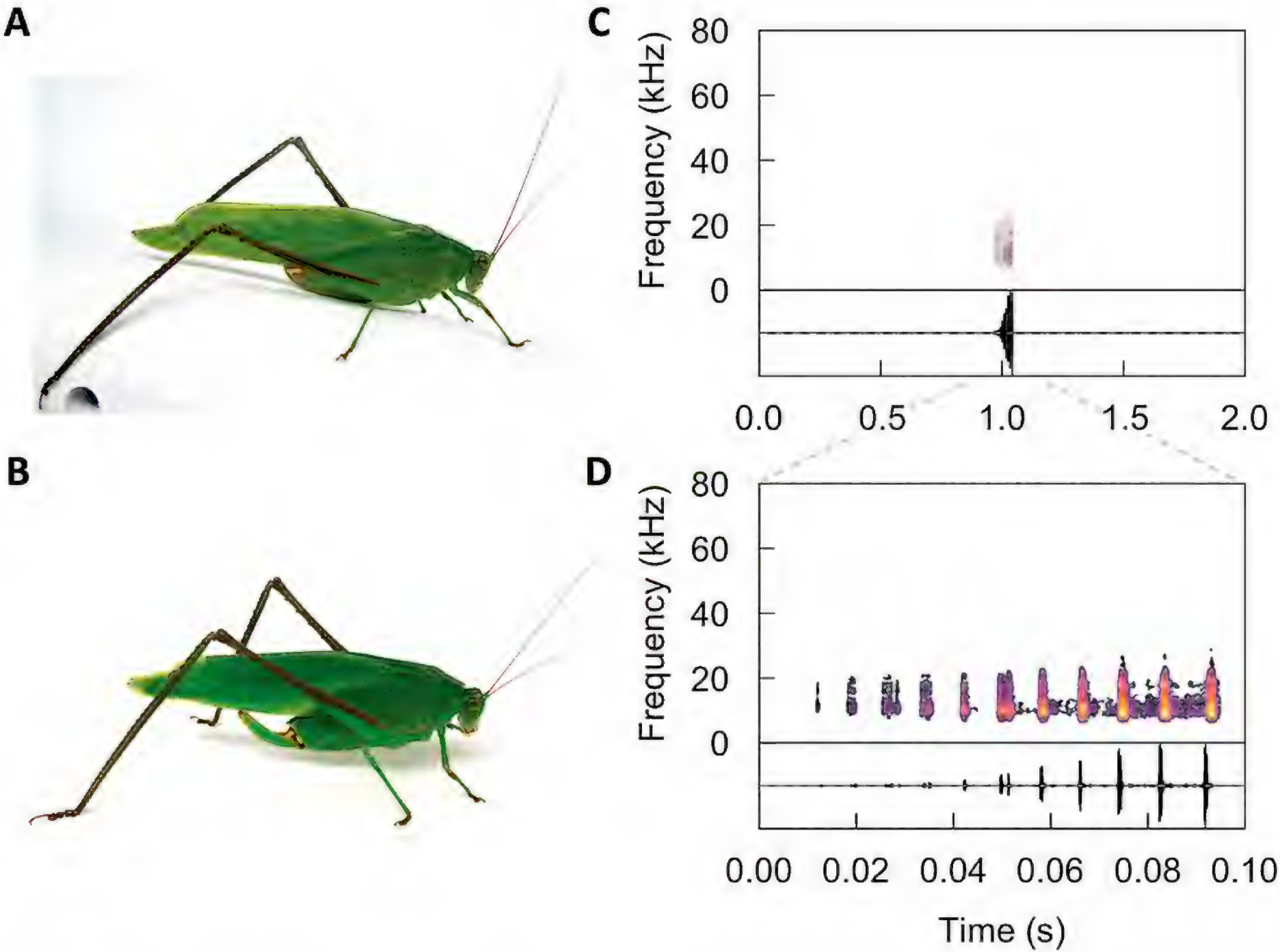The calls of this species were previously described by Falk et al. (2015).

Fig. 21. Photographs and calling song spectrograms of *Ceraia mytra*. **A.** Male (photo credit: H. ter Hofstede); **B.** Female (photo credit: L. Symes); **C.** and **D.** Spectrogram (top panel) and oscillogram (bottom panel) of one call at different time scales.

Table 17. Call pulse parameters of *Ceraia mytra* (9 individuals, 71 calls; mean ± SD); n = number of pulses measured.

Pulse Number (n)	Pulse Duration (ms)	Pulse Period (ms)	Peak Frequency (kHz)	Low Frequency (kHz)	High Frequency (kHz)	Bandwidth (kHz)
1 (71)	1.4 ± 0.5		12.0 ± 1.1	7.9 ± 0.9	17.4 ± 1.7	9.5 ± 2.2
2 (71)	1.6 ± 0.6	7.9 ± 1.2	11.9 ± 1.0	8.0 ± 1.1	17.7 ± 1.9	9.7 ± 2.5
3 (71)	1.7 ± 0.3	7.6 ± 0.6	11.6 ± 0.9	7.8 ± 1.0	17.4 ± 1.4	9.6 ± 1.7
4 (71)	1.5 ± 0.3	8.0 ± 0.7	11.3 ± 0.7	7.7 ± 0.7	16.9 ± 1.3	9.2 ± 1.7
5 (71)	1.3 ± 0.3	8.0 ± 0.5	11.1 ± 0.9	8.0 ± 0.7	16.1 ± 1.4	8.1 ± 1.7
6 (71)	1.4 ± 0.4	8.0 ± 0.5	11.1 ± 0.8	7.6 ± 0.6	16.5 ± 1.7	8.9 ± 1.6
7 (68)	1.6 ± 0.6	8.1 ± 0.5	10.9 ± 0.7	7.8 ± 0.8	17.1 ± 2.3	9.3 ± 2.8
8 (63)	1.6 ± 0.4	8.4 ± 0.6	10.3 ± 1.0	7.5 ± 0.7	16.8 ± 1.5	9.3 ± 2.0
9 (48)	1.8 ± 0.6	8.5 ± 0.8	9.8 ± 0.8	7.1 ± 0.6	15.3 ± 2.3	8.2 ± 2.8
10 (16)	1.1 ± 0.4	8.3 ± 0.3	9.2 ± 0.8	6.7 ± 0.4	14.6 ± 1.2	7.9 ± 1.6

Chloroscirtus discocercus Rehn, 1918
Fig. 22 [MNHN-SO-2019-311, -312, -313, -314, -315, -316, -317, -318, -319, -320, -321, -322]

Chloroscirtus discocercus is a mid-sized (0.59 ± 0.22 g, n = 79), green katydid with narrow wings, sometimes with light yellow stripes along the dorsal margins of the pronotum (Fig. 22A, B). This species is known from Costa Rica, Panama, and Colombia (Cigliano et al. 2020).

The call consists of a series of 4–8 (mean: 6) short pulses (Fig. 22C, D) with a total call duration ranging from ~85–173 ms and having a mean of ~140 ms (Table 1). The peak frequency of the entire call is ~20 kHz with a -20 dB frequency range spanning ~11–26 kHz, giving a bandwidth of ~15 kHz (Table 1). Pulses are fairly constant in amplitude, but the first or last pulse is often of a lower amplitude than the rest of the pulses.

The first pulse in the call is longer in duration than the other pulses, which are similar in duration (Table 18). The first pulse period is also longer in duration than the other periods, which are similar in duration (Table 18). The pulses in the call are all similar in their spectral properties (Table 18). Pulses are usually frequency-modulated, with the first half consisting of a constant frequency component at ~13 kHz, with visible tooth strikes in the oscillogram, followed by a frequency-modulated sweep up to ~20 kHz, often followed by a steep vertical tail at the end (Fig. 22D).

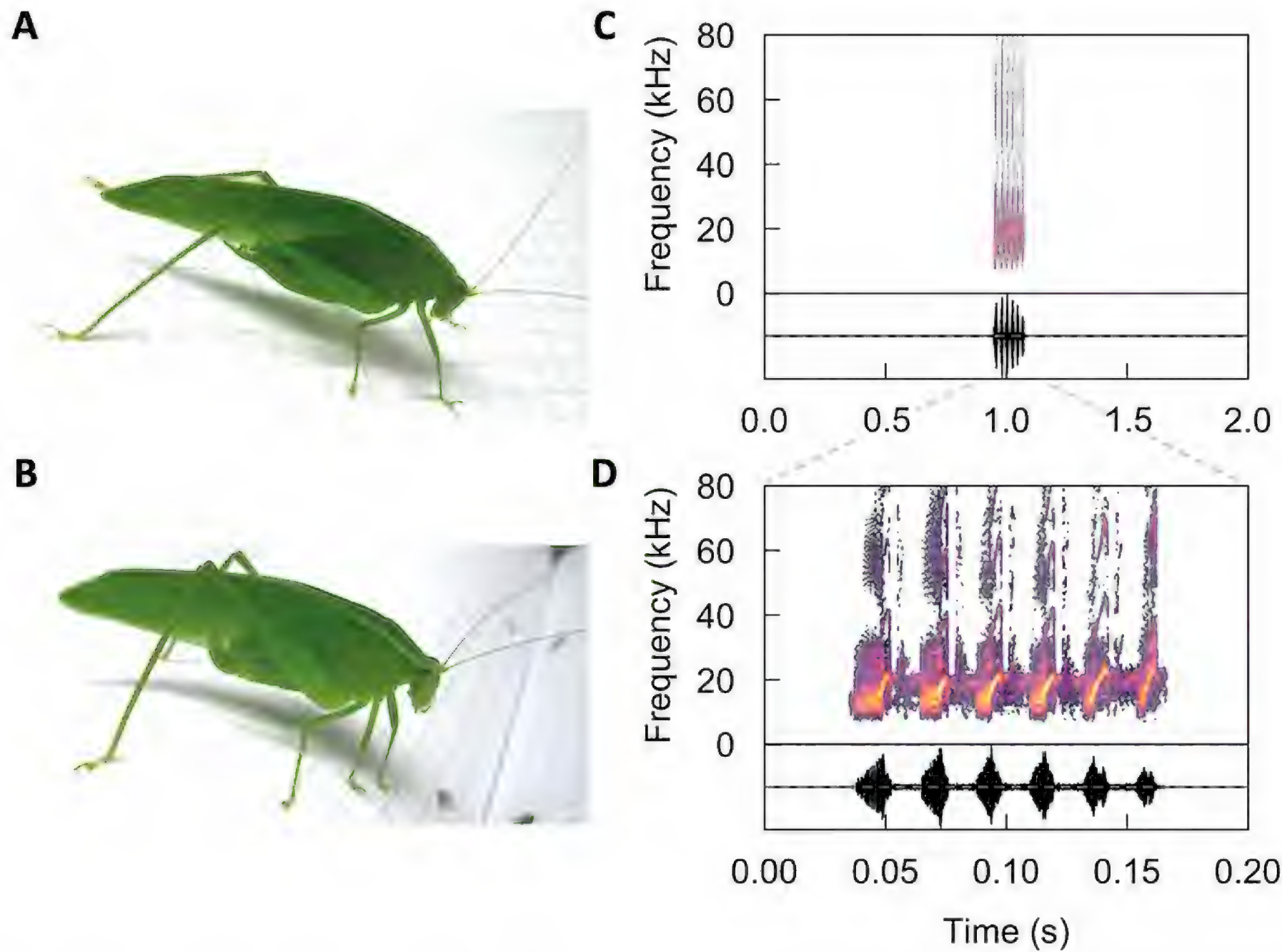The calls of this species were previously described by Symes et al. (2016).

Fig. 22. Photographs and calling song spectrograms of *Chloroscirtus discocercus*. **A.** Male; **B.** Female; **C.** and **D.** Spectrogram (top panel) and oscillogram (bottom panel) of one call at different time scales. Photo credit: H. ter Hofstede.

Table 18. Call pulse parameters of *Chloroscirtus discocercus* (12 individuals, 157 calls; mean ± SD); n = number of pulses measured.

Pulse Number (n)	Pulse Duration (ms)	Pulse Period (ms)	Peak Frequency (kHz)	Low Frequency (kHz)	High Frequency (kHz)	Bandwidth (kHz)
1 (157)	13.7 ± 2.5		17.0 ± 2.7	10.0 ± 1.2	26.9 ± 2.5	16.9 ± 2.8
2 (157)	8.7 ± 2.2	30.0 ± 3.1	18.8 ± 2.5	12.2 ± 2.0	26.1 ± 3.5	13.9 ± 4.4
3 (157)	7.4 ± 2.1	24.2 ± 1.3	18.5 ± 2.8	13.0 ± 2.4	25.5 ± 3.1	12.4 ± 4.5
4 (157)	7.1 ± 1.8	22.7 ± 1.0	19.1 ± 2.3	13.1 ± 2.2	24.8 ± 3.1	11.7 ± 4.3
5 (156)	7.3 ± 1.7	22.1 ± 1.1	19.0 ± 2.2	13.1 ± 2.1	24.5 ± 2.5	11.4 ± 3.8
6 (148)	7.9 ± 1.3	22.3 ± 1.6	19.2 ± 2.4	12.7 ± 1.5	25.5 ± 2.6	12.8 ± 3.6
7 (60)	7.6 ± 1.4	23.3 ± 1.3	18.5 ± 2.2	12.2 ± 1.5	25.4 ± 2.1	13.1 ± 3.3

Dolichocercus latipennis (Brunner von Wattenwyl, 1891)
Fig. 23 [MNHN-SO-2019-344, -345, -346]

Dolichocercus latipennis is a very small (0.21 ± 0.03 g, n = 40) and mostly brown katydid with hind wings that extend significantly beyond the tips of the sharply-angled and narrow tegmina, reminiscent of a wind-dispersed seed (Fig. 23A, B). The dorsal surface of the abdomen is bright green. This species is known from Costa Rica, Panama, and Colombia (Cigliano et al. 2020).

The call consists of a series of 14–17 (mean: 16) short pulses (Fig. 23C, D) with a total call duration ranging from ~282–370 ms and having a mean of ~330 ms (Table 1). The peak frequency of the entire call is ~26 kHz with a -20 dB frequency range spanning ~21–32 kHz, giving a bandwidth of ~11 kHz (Table 1). Pulses usually increase in amplitude over the call with the last two pulses then decreasing in amplitude (Fig. 23C).

The pulses increase in duration across the call (Table 19). The pulse periods are similar in duration (Table 19). The pulses in the call are all similar in their spectral properties (Table 19). Each pulse is a short, downward frequency modulated sweep from ~28–21 kHz (Fig. 23D). In some calls, some pulses have silent gaps within them.

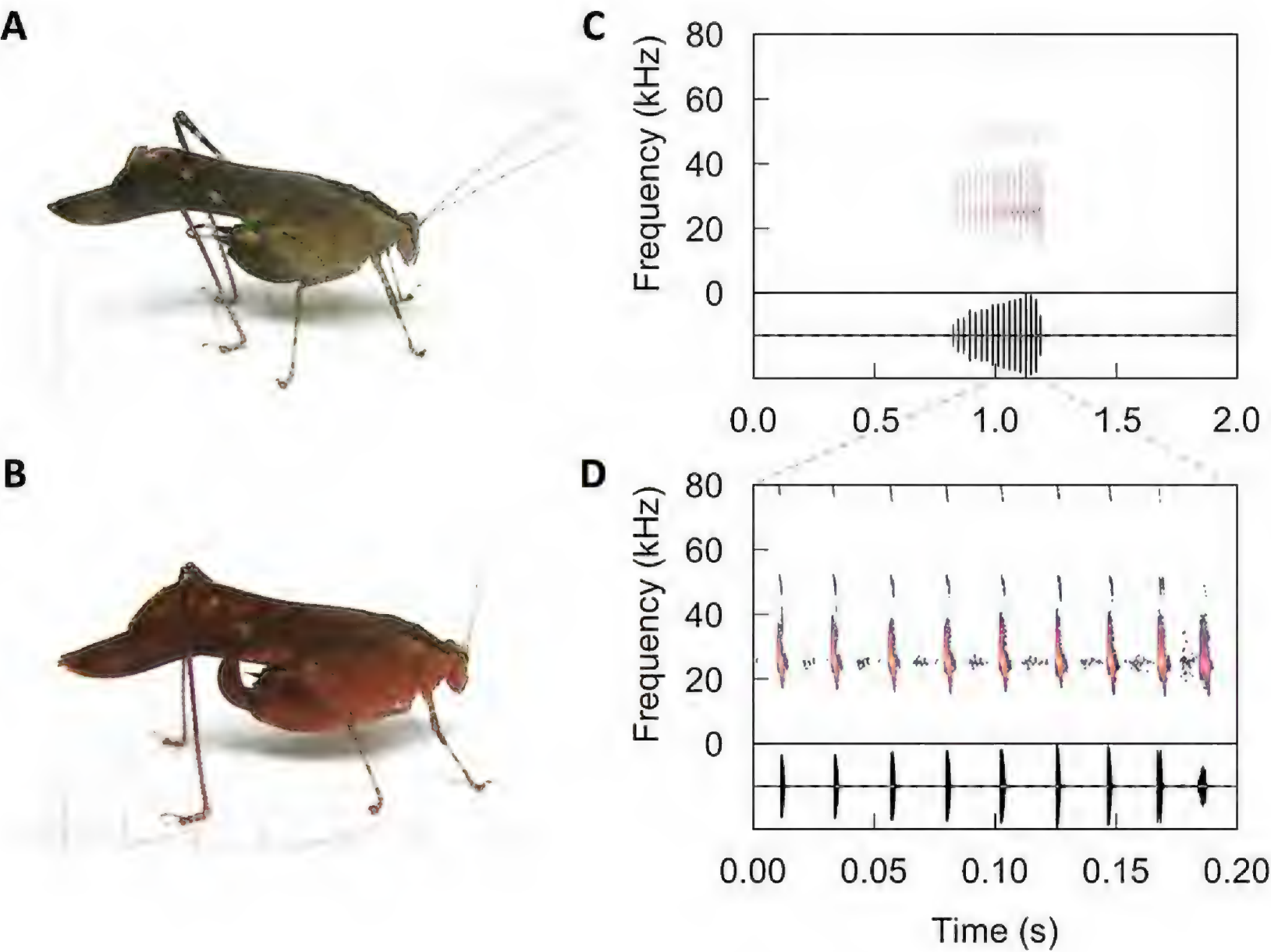This appears to be the first description of the call of this species.

Fig. 23. Photographs and calling song spectrograms of *Dolichocercus latipennis*. **A.** Male; **B.** Female; **C.** and **D.** Spectrogram (top panel) and oscillogram (bottom panel) of one call (**C**) and nine pulses from the same call (**D**). Photo credit: H. ter Hofstede.

Table 19. Call pulse parameters of *Dolichocercus latipennis* (3 individuals, 19 calls; mean ± SD); n = number of pulses measured.

Pulse Number (n)	Pulse Duration (ms)	Pulse Period (ms)	Peak Frequency (kHz)	Low Frequency (kHz)	High Frequency (kHz)	Bandwidth (kHz)
1 (19)	1.0 ± 0.5		27.1 ± 2.2	23.2 ± 0.9	32.0 ± 2.1	8.8 ± 1.4
2 (19)	1.0 ± 0.4	22.5 ± 0.9	26.5 ± 1.8	23.1 ± 1.3	32.0 ± 1.4	8.9 ± 1.7
3 (19)	1.1 ± 0.3	22.9 ± 1.2	26.1 ± 1.1	22.9 ± 0.7	31.3 ± 1.2	8.4 ± 1.0
4 (19)	1.1 ± 0.3	23.2 ± 1.2	26.0 ± 0.9	23.0 ± 0.9	31.1 ± 0.9	8.1 ± 0.8
5 (19)	1.1 ± 0.3	23.2 ± 0.9	26.1 ± 0.8	22.8 ± 0.8	31.1 ± 1.1	8.3 ± 0.6
6 (19)	1.3 ± 0.3	23.0 ± 1.1	26.0 ± 0.6	22.6 ± 0.6	31.1 ± 0.9	8.5 ± 0.6
7 (19)	1.4 ± 0.2	23.1 ± 1.0	25.9 ± 0.4	22.9 ± 0.7	30.9 ± 0.7	8.0 ± 0.5
8 (19)	1.5 ± 0.3	22.9 ± 0.8	26.1 ± 0.6	22.9 ± 0.5	30.8 ± 1.1	7.9 ± 1.2
9 (19)	1.6 ± 0.2	22.8 ± 1.0	26.0 ± 0.6	22.6 ± 0.4	30.4 ± 1.1	7.8 ± 1.3
10 (19)	1.8 ± 0.5	22.8 ± 0.7	26.0 ± 0.6	22.4 ± 0.4	30.6 ± 1.3	8.2 ± 1.5
11 (19)	1.9 ± 0.5	22.8 ± 0.7	25.9 ± 0.6	22.3 ± 0.4	30.7 ± 1.5	8.4 ± 1.5
12 (19)	2.2 ± 0.8	22.5 ± 1.0	26.1 ± 1.0	22.1 ± 0.2	30.8 ± 1.9	8.7 ± 1.9
13 (19)	2.3 ± 0.8	21.8 ± 1.5	25.9 ± 0.9	21.6 ± 0.1	30.8 ± 1.8	9.1 ± 1.8
14 (19)	2.4 ± 0.8	21.3 ± 1.7	25.5 ± 0.8	21.4 ± 0.0	30.9 ± 2.3	9.5 ± 2.3
15 (16)	2.6 ± 1.0	19.9 ± 2.0	25.0 ± 0.4	21.0 ± 0.2	31.5 ± 2.2	10.5 ± 2.4
16 (13)	3.1 ± 0.3	17.9 ± 0.6	23.8 ± 1.0	19.1 ± 0.3	33.2 ± 2.9	14.0 ± 2.9

Ectemna dumicola **Saussure & Pictet, 1897**
Fig. 24 [MNHN-SO-2019-347, -348, -608, -609, -610]

Ectemna dumicola is a mid-sized (0.66 ± 0.11 g, n = 10), green katydid with narrow wings and a thin white and purple stripe running from the eyes, across the lateral surface of the pronotum, and continuing on the leading edge of the tegmen (Fig. 24A, B). This species is known from Panama and Colombia (Cigliano et al. 2020).

The call consists of a series of 3–14 (mean: 10) short pulses (Fig. 24C–F) with a total call duration ranging from ~123–678 ms and having a mean of ~466 ms (Table 1). The peak frequency of the entire call is ~15 kHz with a -20 dB frequency range spanning ~10–26 kHz, giving a bandwidth of ~16 kHz (Table 1). Pulses usually increase in amplitude over the call with the last two pulses often decreasing in amplitude (Fig. 24C–F).

The pulses increase slightly in duration from across the call (Table 20), whereas pulse periods decrease over the call (Table 20). The pulses in the call are all similar in their spectral properties (Table 20).

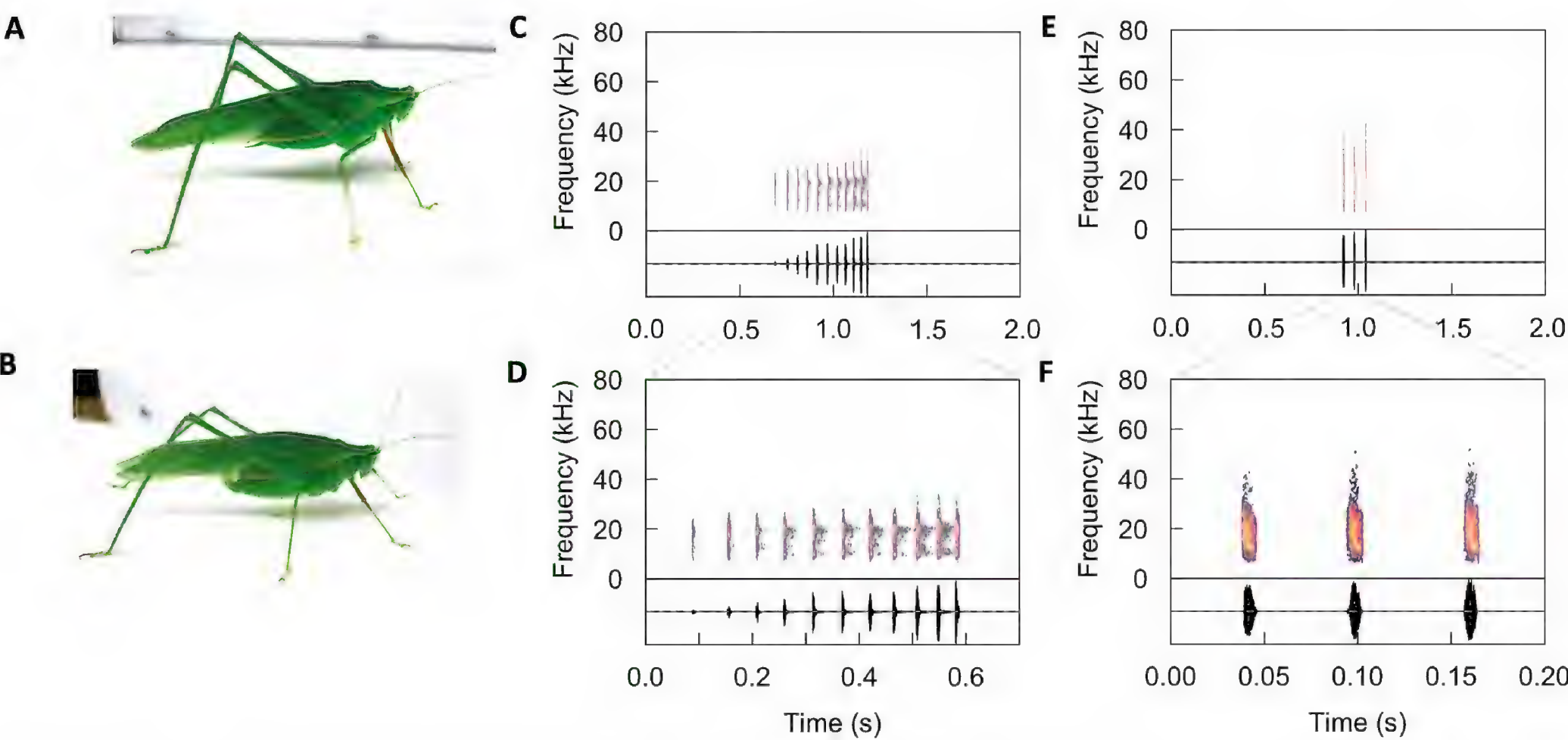This appears to be the first description of the call of this species.

Fig. 24. Photographs and calling song spectrograms of *Ectemna dumicola*. **A.** Male (photo credit: L. Symes); **B.** Female (photo credit: H. ter Hofstede); **C.** and **D.** Spectrogram (top) and oscillogram (bottom) of one call with 11 pulses at different time scales; **E.** and **F.** Spectrogram (top) and oscillogram (bottom) of one call with three pulses at different time scales.

Table 20. Call pulse parameters of *Ectemna dumicola* (5 individuals, 83 calls; mean ± SD); n = number of pulses measured.

Pulse Number (n)	Pulse Duration (ms)	Pulse Period (ms)	Peak Frequency (kHz)	Low Frequency (kHz)	High Frequency (kHz)	Bandwidth (kHz)
1 (83)	5.5 ± 0.6		14.0 ± 1.4	10.0 ± 0.8	24.9 ± 2.2	14.9 ± 2.3
2 (83)	6.2 ± 0.7	60.0 ± 3.7	14.7 ± 1.8	10.3 ± 1.1	24.8 ± 3.5	14.4 ± 3.7
3 (83)	6.2 ± 0.8	56.1 ± 2.3	14.8 ± 1.9	10.4 ± 1.0	24.9 ± 3.4	14.5 ± 3.6
4 (81)	5.9 ± 0.8	57.4 ± 1.6	14.9 ± 2.0	10.4 ± 1.0	24.8 ± 3.3	14.4 ± 3.5
5 (81)	6.0 ± 0.9	56.5 ± 3.1	15.0 ± 2.4	10.4 ± 0.9	24.7 ± 3.2	14.3 ± 3.4
6 (81)	6.4 ± 1.2	54.6 ± 3.7	15.3 ± 2.5	10.5 ± 0.8	25.6 ± 1.7	15.2 ± 1.6
7 (80)	6.8 ± 1.5	52.9 ± 4.6	15.2 ± 2.3	10.4 ± 0.8	26.0 ± 1.6	15.6 ± 1.4
8 (70)	6.9 ± 1.3	48.5 ± 4.4	15.3 ± 2.5	10.3 ± 0.7	26.0 ± 1.4	15.7 ± 1.4
9 (58)	7.4 ± 0.9	41.8 ± 4.3	15.9 ± 2.6	10.3 ± 0.8	26.0 ± 1.2	15.7 ± 1.3
10 (53)	7.0 ± 1.0	39.2 ± 3.6	15.9 ± 2.9	10.2 ± 0.9	25.7 ± 1.1	15.4 ± 1.5
11 (27)	7.0 ± 0.9	38.4 ± 2.2	15.7 ± 2.9	10.3 ± 1.0	24.6 ± 1.5	14.3 ± 2.1
12 (12)	6.9 ± 1.3	38.4 ± 1.7	14.1 ± 0.2	10.7 ± 0.6	23.5 ± 4.3	12.9 ± 4.9

Euceraia atryx Grant, 1964
Fig. 25 [MNHN-SO-2019-662, -663, -666]

Euceraia atryx is a mid-sized (0.67 ± 0.15 g, n = 56), green katydid with narrow wings, orange tarsi, and a pronotum that is yellow on the sides and brown on the dorsal surface (Fig. 25A, B). This species is known from Costa Rica, Panama, Colombia, and Suriname (Cigliano et al. 2020).

The call consists of a series of 11–17 (mean: 14) short pulses (Fig. 25C, D) with a total call duration ranging from ∼0.7–1.7 s and having a mean of ∼1.1 s (Table 1). The peak frequency of the entire call is ∼13 kHz with a -20 dB frequency range spanning ∼11–16 kHz, giving a bandwidth of ∼5 kHz (Table 1). Pulses usually increase and then decrease in amplitude over the call (Fig. 25C, D).

Pulse durations are short, and both pulse durations and pulse periods are consistent across the duration of the call (Table 21). The pulses in the call are all similar in their spectral properties (Table 21).

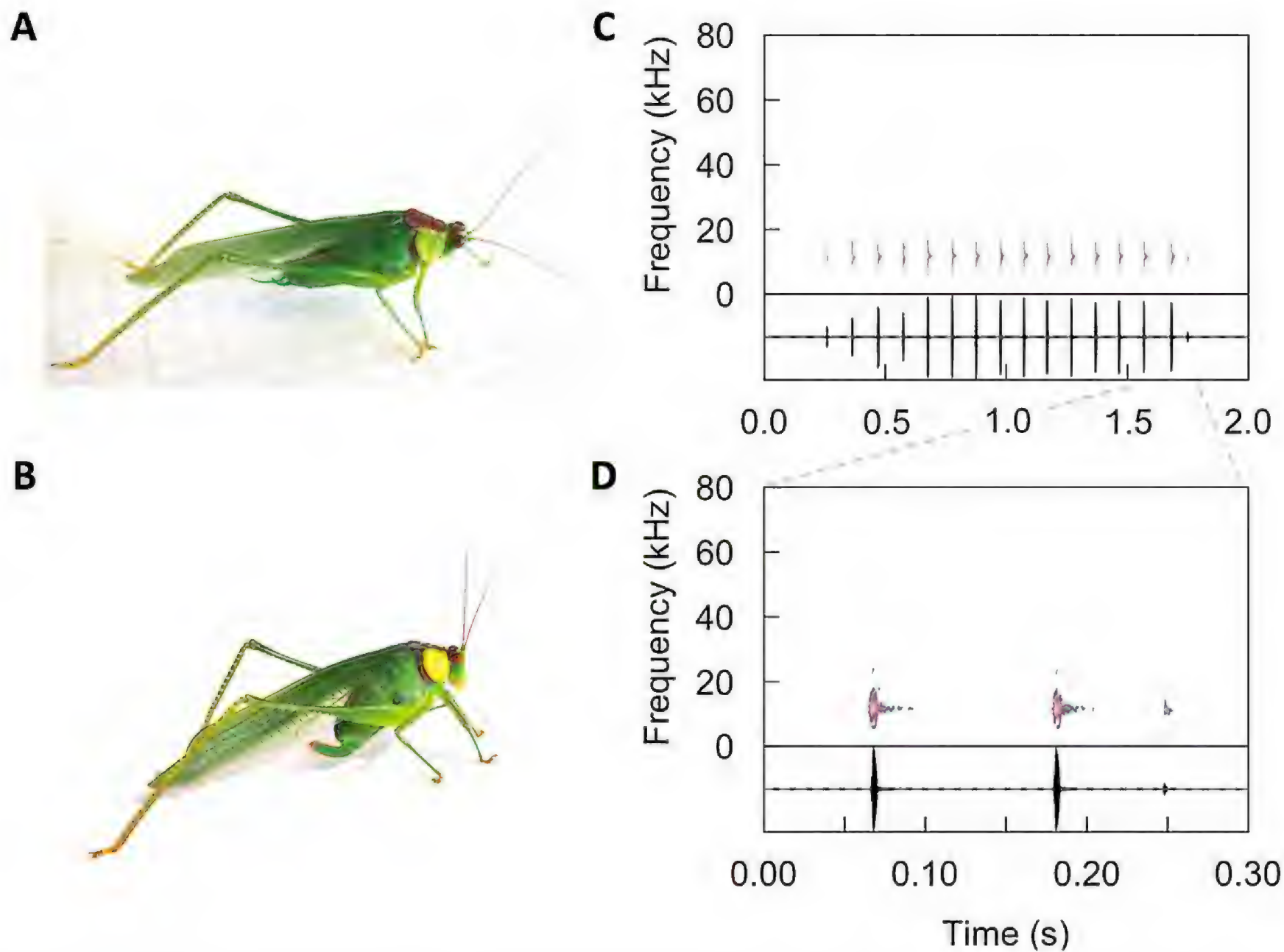This appears to be the first description of the call of this species.

Fig. 25. Photographs and calling song spectrograms of *Euceraia atryx*. **A.** Male (photo credit: H. ter Hofstede); **B.** Female (photo credit: C. Kernan); **C.** and **D.** Spectrogram (top panel) and oscillogram (bottom panel) of one call (**C**) and three pulses from the same call (**D**).

Table 21. Call pulse parameters of *Euceraia atryx* (3 individuals, 14 calls; mean ± SD); n = number of pulses measured.

Pulse Number (n)	Pulse Duration (ms)	Pulse Period (ms)	Peak Frequency (kHz)	Low Frequency (kHz)	High Frequency (kHz)	Bandwidth (kHz)
1 (14)	2.2 ± 0.5		12.8 ± 1.4	11.1 ± 0.9	15.6 ± 1.9	4.5 ± 1.0
2 (14)	2.7 ± 0.2	91.0 ± 19.1	13.1 ± 1.2	11.1 ± 1.0	15.3 ± 1.4	4.2 ± 1.0
3 (14)	3.1 ± 0.3	88.1 ± 17.8	13.1 ± 1.2	11.1 ± 1.1	15.2 ± 1.3	4.1 ± 0.8
4 (14)	3.2 ± 0.1	88.3 ± 17.7	13.1 ± 1.3	11.1 ± 1.3	15.2 ± 0.7	4.1 ± 0.6
5 (14)	3.1 ± 0.2	87.0 ± 18.0	13.0 ± 1.1	11.3 ± 1.1	15.1 ± 0.7	3.8 ± 0.5
6 (14)	2.9 ± 0.3	85.3 ± 17.1	13.1 ± 1.2	11.4 ± 1.0	15.3 ± 0.8	3.9 ± 0.5
7 (14)	2.6 ± 0.3	84.3 ± 17.4	13.2 ± 1.3	11.3 ± 1.1	15.1 ± 1.2	3.8 ± 0.1
8 (14)	2.3 ± 0.6	87.5 ± 16.2	13.3 ± 1.1	11.3 ± 0.9	15.5 ± 1.4	4.2 ± 0.8
9 (14)	2.5 ± 0.5	83.1 ± 16.9	13.4 ± 1.2	11.6 ± 1.5	15.2 ± 0.9	3.6 ± 0.6
10 (14)	2.4 ± 0.6	81.8 ± 17.6	13.3 ± 1.3	11.7 ± 1.4	15.4 ± 0.9	3.7 ± 0.7
11 (14)	2.4 ± 0.8	82.5 ± 17.3	13.3 ± 1.4	11.6 ± 1.5	15.4 ± 1.0	3.8 ± 0.9
12 (11)	2.2 ± 0.7	83.0 ± 17.0	13.4 ± 1.2	11.7 ± 1.5	15.1 ± 0.9	3.4 ± 0.8
13 (8)	2.4 ± 0.8	90.4 ± 15.9	13.0 ± 1.6	11.4 ± 1.4	14.8 ± 1.5	3.4 ± 0.0
14 (6)	2.7 ± 0.5	95.8 ± 10.0	12.8 ± 1.2	10.9 ± 1.0	14.5 ± 0.8	3.6 ± 0.3

Euceraia insignis **Hebard, 1927**
Fig. 26 [MNHN-SO-2019-1090, -1091, -1092]

Euceraia insignis is a mid-sized (0.58 ± 0.08 g, n = 37) katydid with narrow wings, a neon green pronotum, orange tarsi, and hind femurs that are green at the proximal end and black at the distal end (Fig. 26A, B). This species is widely distributed throughout Central America (Nicaragua, Costa Rica, and Panama) and northeastern South America (Cigliano et al. 2020).

The call consists of a series of 12–18 (mean: 16) short pulses (Fig. 26C, D) with a total call duration ranging from ~1.0–1.9 s and having a mean of ~1.6 s (Table 1). The peak frequency of the entire call is ~13 kHz with a -20 dB frequency range spanning ~10–15 kHz, giving a bandwidth of ~5 kHz (Table 1). Pulses usually increase and then decrease in amplitude over the call (Fig. 26C, D).

The first two pulses are shorter than the rest of the pulses in the call, and the pulse period decreases slightly over the call (Table 22). The pulses in the call are all similar in their spectral properties (Table 22).

This appears to be the first description of the call of this species.
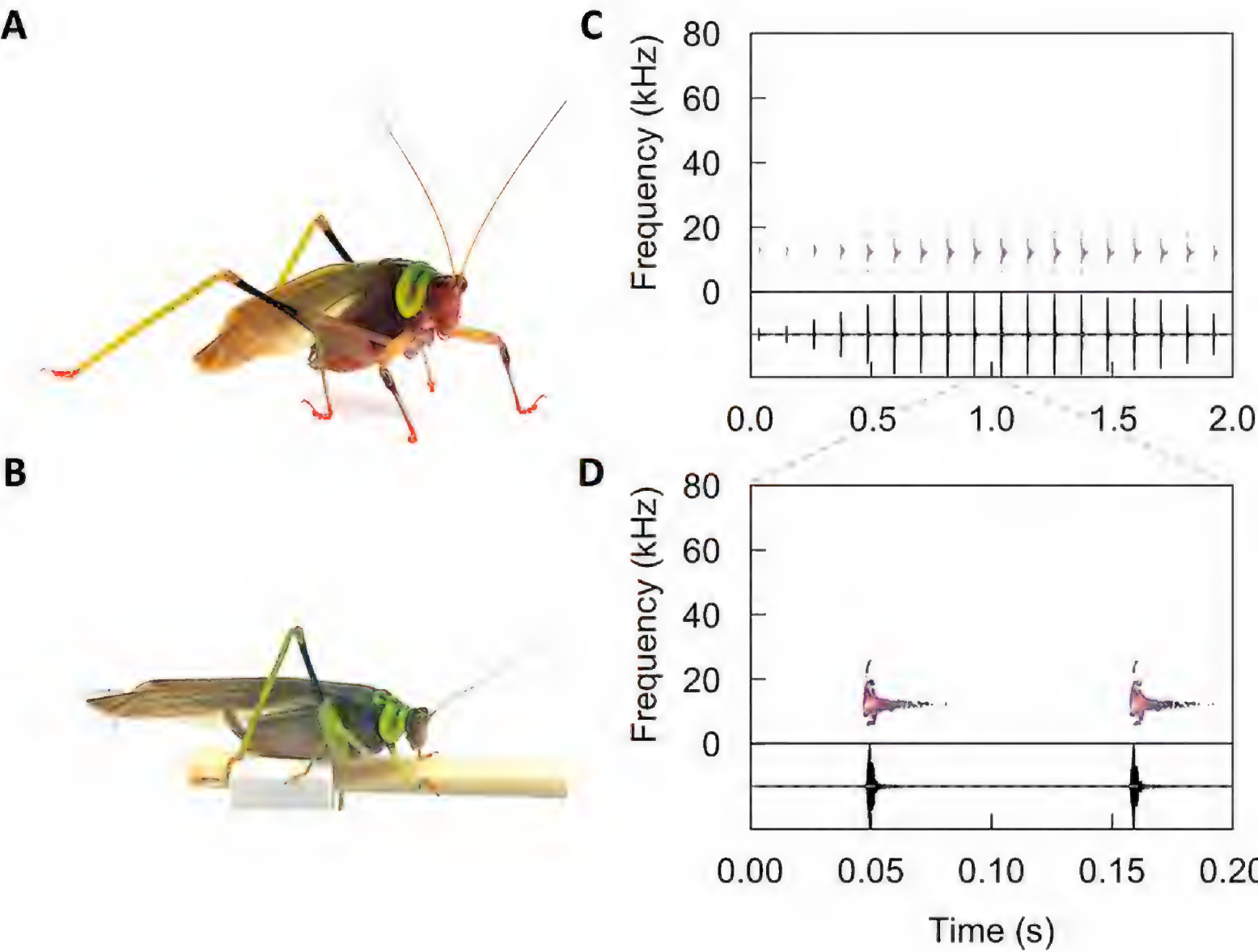
Fig. 26. Photographs and calling song spectrograms of *Euceraia insignis*. **A.** Male (photo credit: C. Kernan); **B.** Female (photo credit: C. Wilson); **C.** and **D.** Spectrogram (top panel) and oscillogram (bottom panel) of one call (**C**) and two pulses from the same call (**D**).

Table 22. Call pulse parameters of *Euceraia insignis* (3 individuals, 21 calls; mean ± SD); n = number of pulses measured.

Pulse Number (n)	Pulse Duration (ms)	Pulse Period (ms)	Peak Frequency (kHz)	Low Frequency (kHz)	High Frequency (kHz)	Bandwidth (kHz)
1 (21)	1.5 ± 0.2		12.1 ± 0.5	10.3 ± 0.9	14.5 ± 0.3	4.3 ± 0.7
2 (21)	1.7 ± 0.1	110.8 ± 3.2	12.5 ± 0.1	11.2 ± 0.1	14.3 ± 0.2	3.1 ± 0.2
3 (21)	2.0 ± 0.3	108.0 ± 4.3	12.8 ± 0.3	11.4 ± 0.5	14.6 ± 0.5	3.1 ± 0.3
4 (21)	2.7 ± 0.4	108.4 ± 3.7	12.8 ± 0.3	10.9 ± 0.3	14.6 ± 0.5	3.7 ± 0.7
5 (21)	3.2 ± 0.6	106.7 ± 4.0	12.7 ± 0.5	10.7 ± 0.5	14.5 ± 0.7	3.8 ± 1.2
6 (21)	3.3 ± 0.4	105.6 ± 5.2	12.7 ± 0.6	10.6 ± 0.2	14.4 ± 0.7	3.9 ± 0.8
7 (21)	3.1 ± 0.3	104.9 ± 5.6	12.8 ± 0.5	10.6 ± 0.6	14.4 ± 0.7	3.8 ± 1.2
8 (21)	3.0 ± 0.1	104.3 ± 6.3	12.8 ± 0.5	10.3 ± 0.4	14.6 ± 0.9	4.3 ± 1.2
9 (21)	3.1 ± 0.4	103.6 ± 6.2	12.6 ± 0.5	10.3 ± 0.3	14.5 ± 0.8	4.2 ± 1.1
10 (21)	3.0 ± 0.2	104.0 ± 7.3	12.8 ± 0.5	10.5 ± 0.2	14.5 ± 0.8	4.0 ± 0.9
11 (21)	3.1 ± 0.2	102.8 ± 6.3	12.5 ± 0.9	10.5 ± 0.3	14.5 ± 0.7	4.0 ± 1.0
12 (21)	3.1 ± 0.4	103.5 ± 7.3	12.7 ± 0.7	10.5 ± 0.2	14.5 ± 0.8	4.0 ± 1.0
13 (20)	3.3 ± 0.5	103.5 ± 7.0	12.7 ± 0.7	10.4 ± 0.3	14.4 ± 0.7	4.0 ± 1.0
14 (19)	2.9 ± 0.1	102.4 ± 6.1	12.5 ± 0.8	10.4 ± 0.3	14.6 ± 0.8	4.2 ± 1.1
15 (17)	3.0 ± 0.1	103.5 ± 7.3	12.7 ± 0.6	10.6 ± 0.1	14.5 ± 0.8	3.9 ± 0.9
16 (11)	2.8 ± 0.2	102.6 ± 6.8	12.7 ± 0.6	10.7 ± 0.0	14.5 ± 0.8	3.8 ± 0.7

Hetaira sp.
Fig. 27

Hetaira is a very small (0.15 ± 0.02 g, n = 6) katydid with green and brown coloration, white tarsi, and a solid green dorsal surface of the pronotum (Fig. 27A). We were not able to identify this katydid to species. The calls recorded from these individuals are all the same and can be readily distinguished from other katydid species collected in Panama.

The call consists of a series of three pulses (Fig. 27B, C) with a total call duration ranging from 33–40 ms and having a mean of ~36 ms (Table 1). The peak frequency of the entire call is ~25 kHz with a -20 dB frequency range spanning ~22–30 kHz, giving a bandwidth of ~8 kHz (Table 1). Pulse amplitudes are constant or can increase across the call (Fig. 27C).

Pulse durations increase slightly across the call, whereas pulse periods are similar to each other (Table 23). The pulses in the call are all similar in their spectral properties (Table 23). Pulses sometimes have short silent gaps within them, such that they appear like two very short pulses produced in rapid succession.

This appears to be the first description of the call of this species.
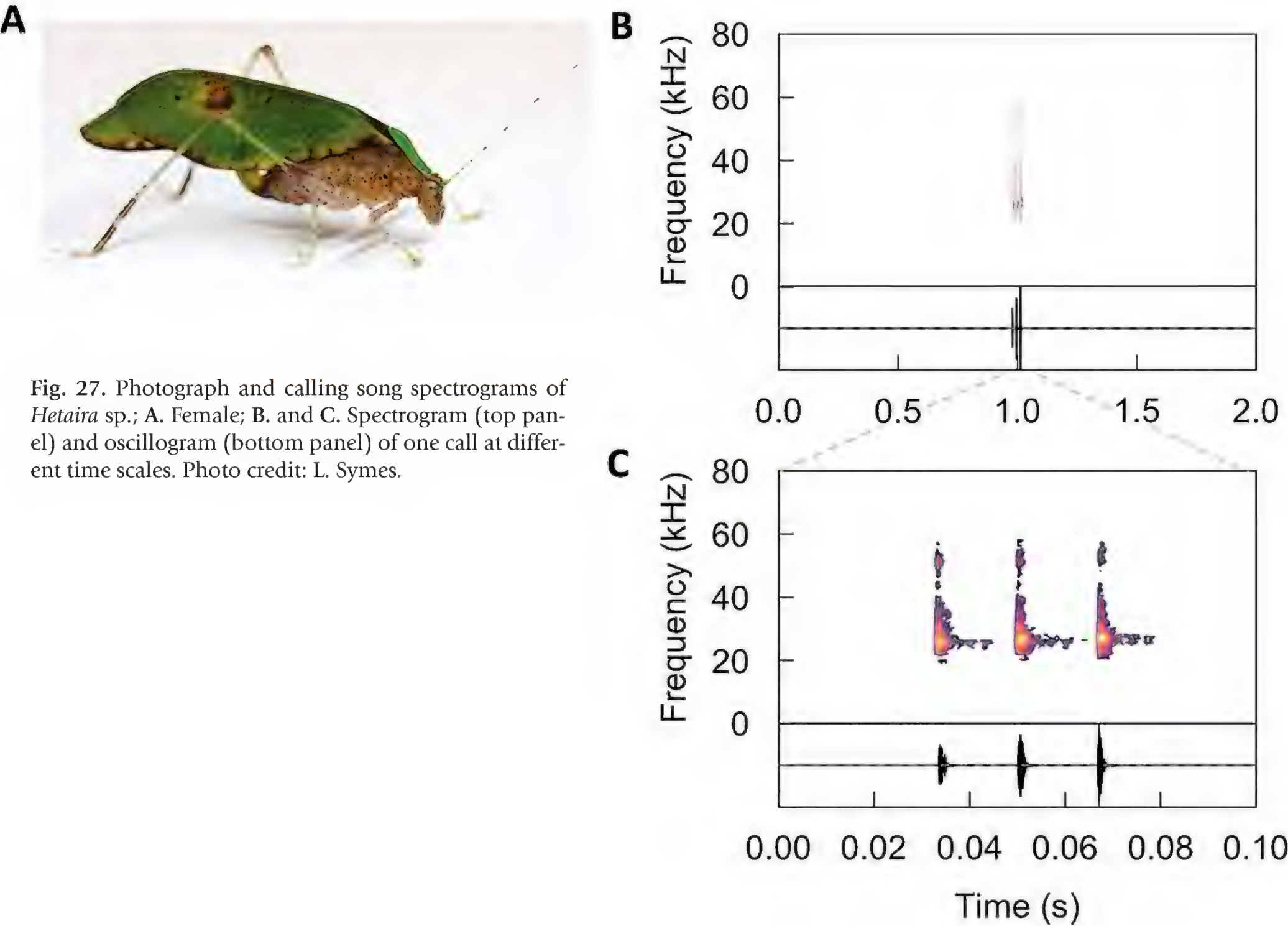
Fig. 27. Photograph and calling song spectrograms of *Hetaira* sp.; **A.** Female; **B.** and **C.** Spectrogram (top panel) and oscillogram (bottom panel) of one call at different time scales. Photo credit: L. Symes.

Table 23. Call pulse parameters of *Hetaira* sp. (3 individuals, 13 calls; mean ± SD); n = number of pulses measured.

Pulse Number (n)	Pulse Duration (ms)	Pulse Period (ms)	Peak Frequency (kHz)	Low Frequency (kHz)	High Frequency (kHz)	Bandwidth (kHz)
1 (13)	1.1 ± 0.3		24.8 ± 0.8	22.0 ± 1.4	28.6 ± 1.3	6.6 ± 2.4
2 (13)	1.2 ± 0.4	17.2 ± 1.5	25.0 ± 1.2	22.4 ± 1.3	28.0 ± 2.1	5.6 ± 0.8
3 (13)	1.4 ± 0.2	17.5 ± 1.5	25.0 ± 1.2	22.3 ± 1.7	29.0 ± 1.7	6.6 ± 0.3

Hyperphrona irregularis Brunner von Wattenwyl, 1891
Fig. 28 [MNHN-SO-2019-1093, -1094, -1095]

Hyperphrona irregularis is a mid-sized (0.98 ± 0.29 g, n = 25), green katydid with highly conspicuous blue and black banding on the dorsal surface of the abdomen and three small, dark spots on the broad tegmina (Fig. 28A, B). This species is known from Nicaragua, Panama, and Colombia (Cigliano et al. 2020).

The call consists of a single pulse with a duration ~9 ms (Table 1; Fig. 28C, D). The peak frequency of the call is ~16 kHz, with a -20 dB range spanning 15–19 kHz, giving a bandwidth of ~4 kHz. The frequency increases slightly over the call from ~15 to 18 kHz in a sine-shaped wave (Fig. 28D).

This appears to be the first description of the call of this species.
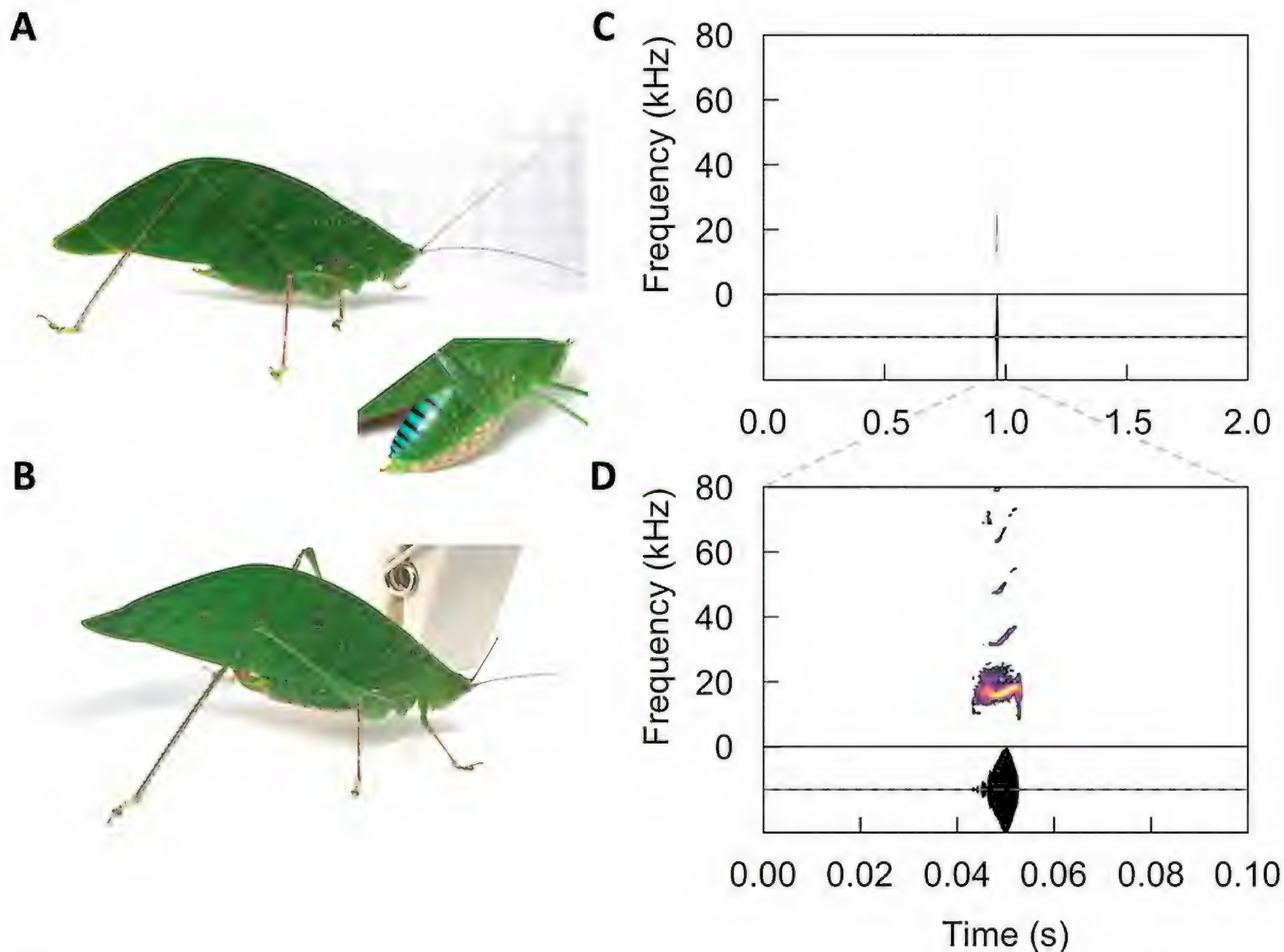
Fig. 28. Photographs and calling song spectrograms of *Hyperphrona irregularis*. **A.** Male, inset showing blue stripes on dorsal surface of abdomen (photo credit: H. ter Hofstede); **B.** Female (photo credit: C. Wilson); **C.** and **D.** Spectrogram (top panel) and oscillogram (bottom panel) of one call at different time scales.

Lamprophyllum bugabae Hebard, 1927

Fig. 29 [MNHN-SO-2019-1283, -1284, -1285, -1286, -1287, -1288, -1289, -1290, -1291, -1292, -1293, -1294, -1295, -1296]

Lamprophyllum bugabae is a large (1.61 ± 0.28 g, n = 101), green katydid with broad wings and a black and yellow line on the leading edge of the tegmen (Fig. 29A). This species is only known from Panama (Cigliano et al. 2020).

The call consists of a series of 3–8 (mean: 7) long pulses (Fig. 29C, D) with a total call duration ranging from ∼260–750 ms and having a mean of ∼615 ms (Table 1). The peak frequency of the entire call is ∼10 kHz with a -20 dB frequency range spanning ∼7–19 kHz, giving a bandwidth of ∼12 kHz (Table 1). Pulses usually increase and then decrease in amplitude over the call (Fig. 29C, D).

Pulse durations usually increase and then decrease across the call, whereas pulse periods are similar in duration (Table 24). The pulses in the call are all similar in their spectral properties (Table 24). Individual tooth strikes in each pulse are clearly visible on the oscillogram and are much more closely spaced than in *Lamprophyllum micans* (compare Fig. 29C and Fig. 30D). The peak frequency of each tooth strike decreases across each pulse from ∼15 to 9 kHz.

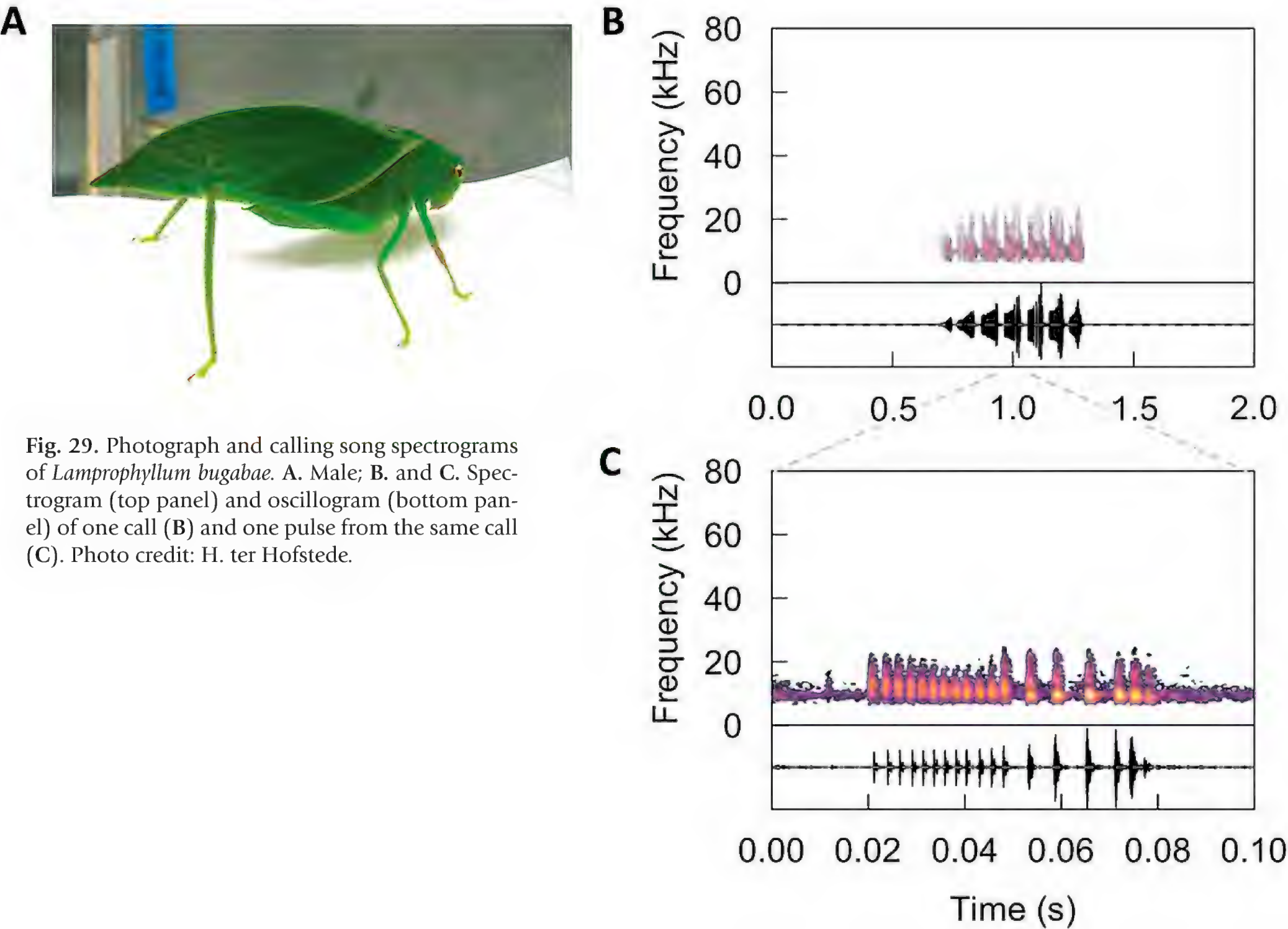The calls of this species were previously described by Falk et al. (2015).

Fig. 29. Photograph and calling song spectrograms of *Lamprophyllum bugabae*. **A.** Male; **B.** and **C.** Spectrogram (top panel) and oscillogram (bottom panel) of one call (**B**) and one pulse from the same call (**C**). Photo credit: H. ter Hofstede.

Table 24. Call pulse parameters of *Lamprophyllum bugabae* (14 individuals, 207 calls; mean ± SD); n = number of pulses measured.

Pulse Number (n)	Pulse Duration (ms)	Pulse Period (ms)	Peak Frequency (kHz)	Low Frequency (kHz)	High Frequency (kHz)	Bandwidth (kHz)
1 (207)	60.5 ± 9.4		10.0 ± 0.5	6.5 ± 0.2	17.9 ± 1.8	11.4 ± 1.9
2 (207)	72.7 ± 7.6	82.6 ± 9.3	9.8 ± 0.6	6.8 ± 0.2	18.4 ± 1.5	11.6 ± 1.6
3 (207)	74.8 ± 7.2	94.3 ± 8.1	9.9 ± 0.6	7.1 ± 0.2	19.0 ± 1.1	11.9 ± 1.1
4 (206)	73.4 ± 7.1	96.3 ± 7.5	9.9 ± 0.6	7.2 ± 0.2	19.4 ± 0.9	12.2 ± 0.9
5 (202)	71.3 ± 8.0	95.9 ± 6.7	9.7 ± 0.4	7.2 ± 0.2	19.5 ± 0.8	12.3 ± 0.7
6 (199)	70.1 ± 7.5	93.9 ± 6.6	9.8 ± 0.6	7.2 ± 0.2	19.5 ± 0.8	12.3 ± 0.8
7 (157)	64.4 ± 7.5	94.8 ± 10.3	9.9 ± 0.9	7.1 ± 0.4	19.5 ± 0.7	12.4 ± 0.8
8 (62)	59.8 ± 5.5	87.6 ± 2.7	10.3 ± 0.8	6.9 ± 0.3	19.3 ± 1.2	12.4 ± 1.1

Lamprophyllum micans **Hebard, 1924**
Fig. 30 [MNHN-SO-2019-1297, -1298, -1299, -1300, -1301,
-1302, -1303, -1304, -1305, -1306, -1307]

Lamprophyllum micans is a medium-to-large (0.99 ± 0.17 g, n = 153), green katydid with broad wings, a thin black and yellow line on the leading edge of the tegmen, and a black eye stripe that extends below the eye (Fig. 30A, B). Males have a black saddle across the stridulatory area. This species is known from Nicaragua, Costa Rica, Panama, and Colombia (Cigliano et al. 2020).

The call consists of a series of 7–9 (mean: 8) long pulses (Fig. 30C, D) with a total call duration ranging from ~675–900 ms and having a mean of ~800 ms (Table 1). The peak frequency of the entire call is ~17 kHz with a -20 dB frequency range spanning ~13–24 kHz, giving a bandwidth of ~11 kHz (Table 1). Pulses usually increase and then decrease in amplitude over the call (Fig. 30C, D).

Pulse durations usually increase across the call, whereas pulse periods are more similar in duration (Table 25). The pulses in the call are all similar in their spectral properties (Table 25). Individual tooth strikes in each pulse are clearly visible on the oscillogram and are fewer and much more sparsely spaced than in *Lamprophyllum bugabae* (compare Fig. 30D and Fig. 29C). Unlike for *L. bugabae*, the peak frequency of each tooth strike is the same.

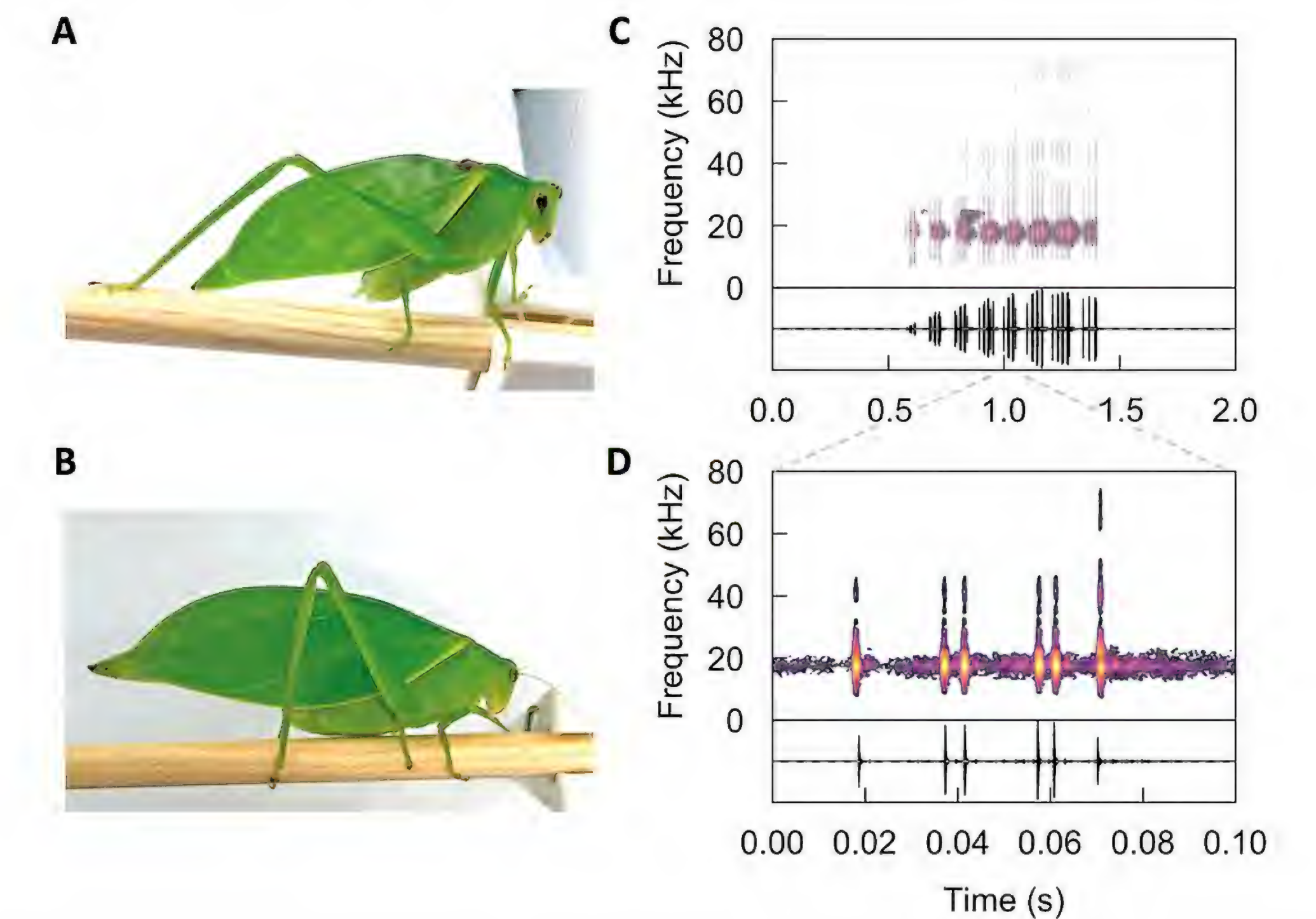The calls of this species were previously described by Symes et al. (2016).

Fig. 30. Photographs and calling song spectrograms of *Lamprophyllum micans*. **A.** Male; **B.** Female; **C.** and **D.** Spectrogram (top panel) and oscillogram (bottom panel) of one call (**C**) and one pulse from the same call (**D**). Photo credit: C. Wilson.

Table 25. Call pulse parameters of *Lamprophyllum micans* (11 individuals, 55 calls; mean ± SD); n = number of pulses measured.

Pulse Number (n)	Pulse Duration (ms)	Pulse Period (ms)	Peak Frequency (kHz)	Low Frequency (kHz)	High Frequency (kHz)	Bandwidth (kHz)
1 (55)	43.8 ± 5.4		17.0 ± 1.2	13.3 ± 0.7	23.3 ± 0.8	10.0 ± 0.8
2 (55)	44.2 ± 2.4	105.6 ± 5.6	17.1 ± 1.1	13.4 ± 0.7	23.2 ± 0.5	9.8 ± 0.6
3 (55)	45.0 ± 2.7	107.3 ± 5.0	17.1 ± 1.2	13.1 ± 0.6	23.4 ± 0.6	10.3 ± 0.7
4 (55)	46.9 ± 3.1	102.8 ± 7.3	17.1 ± 1.2	13.0 ± 0.6	23.5 ± 0.7	10.6 ± 0.7
5 (55)	49.6 ± 4.6	102.1 ± 5.2	17.3 ± 1.3	13.0 ± 0.6	23.7 ± 0.8	10.7 ± 0.6
6 (55)	57.3 ± 7.6	101.7 ± 6.8	17.5 ± 1.4	13.1 ± 0.8	23.6 ± 0.8	10.5 ± 0.8
7 (55)	63.3 ± 8.6	106.7 ± 4.3	17.7 ± 1.4	13.1 ± 0.9	23.7 ± 1.0	10.6 ± 0.9
8 (52)	67.9 ± 5.6	112.1 ± 8.6	17.7 ± 1.3	12.9 ± 0.8	23.7 ± 0.9	10.7 ± 0.8

Microcentrum championi Saussure & Pictet, 1898
Fig. 31 [MNHN-SO-2019-1308, -1309, -1310, -1311]

Microcentrum championi is a mid-sized (0.93 ± 0.08 g, n = 62), robust, green katydid with broad wings and yellow mouth-parts (Fig. 31A, B). This species is known from Panama and Colombia (Cigliano et al. 2020).

The call consists of a series of three pulses (Fig. 31C, D) with a total call duration ranging from ~370–668 ms and having a mean of ~472 ms (Table 1). The peak frequency of the entire call is ~10 kHz with a -20 dB frequency range spanning ~7–17 kHz, giving a bandwidth of ~10 kHz (Table 1). Pulses increase in amplitude over the call (Fig. 31C, D).

The first pulse is shorter in duration than the other two pulses (Table 26). The pulses in the call are all similar in their spectral properties (Table 26). Individual tooth strikes in each pulse are clearly visible on the oscillogram (Fig. 31D).
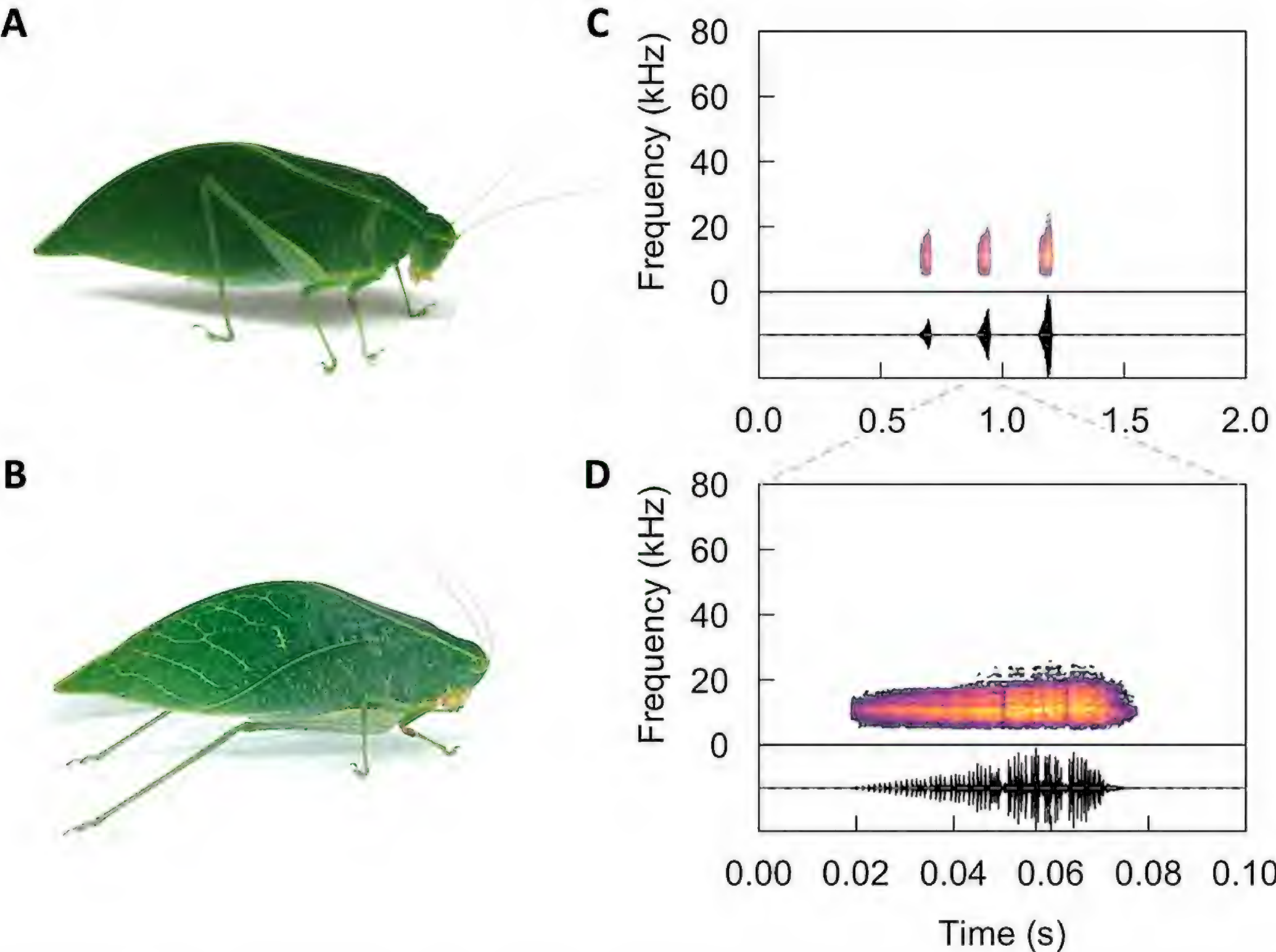
Fig. 31. Photographs and calling song spectrograms of *Microcentrum championi*. **A.** Male (photo credit: H. ter Hofstede); **B.** Female (photo credit: C. Wilson); **C.** and **D.** Spectrogram (top panel) and oscillogram (bottom panel) of one call (**C**) and one pulse from the same call (**D**).

Table 26. Call pulse parameters of *Microcentrum championi* (4 individuals, 20 calls; mean ± SD); n = number of pulses measured.

Pulse Number (n)	Pulse Duration (ms)	Pulse Period (ms)	Peak Frequency (kHz)	Low Frequency (kHz)	High Frequency (kHz)	Bandwidth (kHz)
1 (20)	38.8 ± 7.1		10.1 ± 0.4	6.8 ± 0.2	15.3 ± 1.3	8.5 ± 1.3
2 (20)	48.3 ± 4.9	195.1 ± 23.4	10.2 ± 0.5	7.0 ± 0.2	15.5 ± 1.3	8.5 ± 1.3
3 (20)	49.1 ± 4.8	215.4 ± 24.0	10.2 ± 0.4	7.1 ± 0.2	16.4 ± 1.1	9.3 ± 1.0

Microcentrum "polka"
Fig. 32

Microcentrum "polka" is a large (1.20 ± 0.12 g, n = 117), green katydid with yellow dots along the leading edge of the tegmen (Fig. 32A, B). We were not able to identify these individuals to species and provide the temporary species name "polka" because of the yellow dots on the wings. The calls recorded from these individuals are all the same and can be readily distinguished from other katydid species collected in Panama.

The call consists of a series of 3–15 short pulses (mean: 8; Fig. 32C, D) with a total call duration ranging from 2.2–13.6 s and having a mean of ~6.3 s (Table 1). The peak frequency of the entire call is ~10 kHz with a -20 dB frequency range spanning ~7–14 kHz, giving a bandwidth of ~7 kHz (Table 1). The pulse amplitude is highly variable within and between individuals and can increase, decrease, or stay constant in amplitude.

Both pulse durations and pulse periods are consistent across the duration of the call (Table 27). The pulses in the call are all similar in their spectral properties (Table 27).
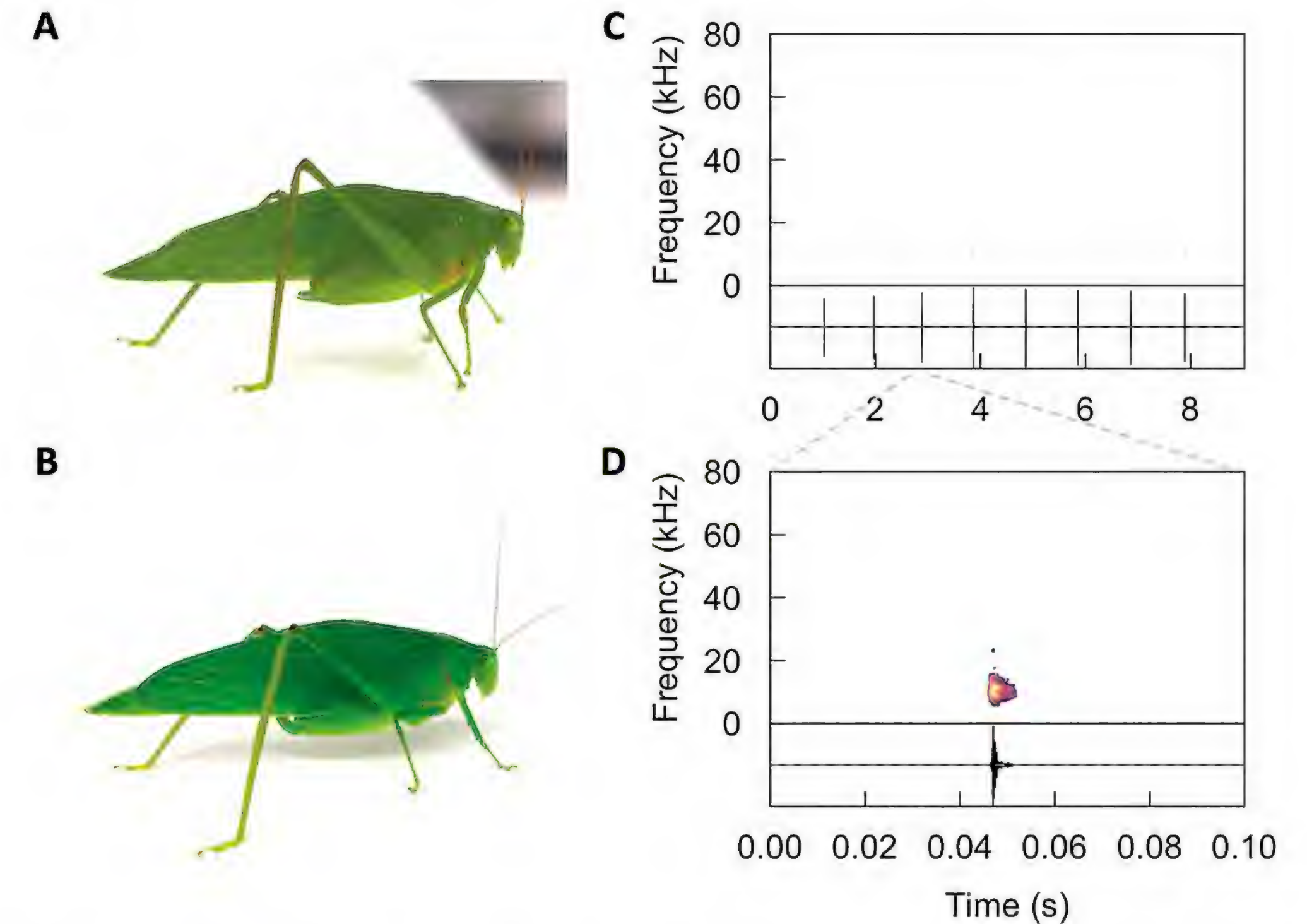
Fig. 32. Photographs and calling song spectrograms of *Microcentrum* "polka". **A.** Male (photo credit: C. Kernan); **B.** Female (photo credit: L. Symes); **C.** and **D.** Spectrogram (top panel) and oscillogram (bottom panel) of one call (**C**) and one pulse from the same call (**D**).

Table 27. Call pulse parameters of *Microcentrum* "polka" (8 individuals, 73 calls; mean ± SD); n = number of pulses measured.

Pulse Number (n)	Pulse Duration (ms)	Pulse Period (ms)	Peak Frequency (kHz)	Low Frequency (kHz)	High Frequency (kHz)	Bandwidth (kHz)
1 (73)	1.7 ± 0.3		9.7 ± 0.4	7.2 ± 0.3	13.4 ± 0.5	6.2 ± 0.6
2 (73)	1.7 ± 0.3	971.0 ± 46.5	9.7 ± 0.4	7.2 ± 0.3	13.5 ± 0.5	6.3 ± 0.5
3 (73)	1.9 ± 0.3	964.9 ± 44.2	9.7 ± 0.5	7.3 ± 0.3	13.6 ± 0.6	6.3 ± 0.5
4 (72)	2.0 ± 0.3	947.6 ± 47.0	9.7 ± 0.5	7.3 ± 0.3	13.5 ± 0.6	6.2 ± 0.5
5 (67)	2.0 ± 0.4	935.9 ± 51.4	9.8 ± 0.5	7.3 ± 0.3	13.6 ± 0.7	6.3 ± 0.5
6 (56)	2.1 ± 0.3	936.9 ± 55.2	9.7 ± 0.4	7.3 ± 0.4	13.6 ± 0.6	6.3 ± 0.5
7 (42)	2.1 ± 0.4	938.8 ± 57.8	9.8 ± 0.5	7.4 ± 0.4	13.7 ± 0.6	6.3 ± 0.4
8 (31)	2.0 ± 0.5	940.6 ± 65.6	9.6 ± 0.5	7.4 ± 0.4	13.7 ± 0.8	6.3 ± 0.5
9 (20)	2.2 ± 0.5	949.3 ± 75.4	9.5 ± 0.6	7.4 ± 0.4	13.9 ± 0.8	6.5 ± 0.6
10 (13)	2.7 ± 0.5	961.7 ± 79.9	9.7 ± 1.0	7.4 ± 0.5	13.5 ± 0.8	6.1 ± 0.5

Montezumina bradleyi **Hebard, 1927**
Fig. 33 [MNHN-SO-2019-1312, -1313, -1314]

Montezumina bradleyi is a very small (0.16 ± 0.03 g, n = 15), green katydid with narrow tegmina, hind wings that stick out significantly past the tips of the tegmina, elongated eyes, and an "E"-shaped marking on the inner surface of the forefemur (Fig. 33A). This species is known from Costa Rica and Panama (Cigliano et al. 2020).

The call consists of a single pulse with a duration of ∼32 ms (Table 1; Fig. 33B, C). The peak frequency of the call is ∼30 kHz, with a -20 dB range spanning 19–47 kHz, giving a very broad bandwidth of ∼28 kHz. The peak frequency decreases over the call from ∼40 kHz at the start of the call to ∼20 kHz at the end of the call (Fig. 33C). Individual tooth strikes are visible on the oscillogram (Fig. 33C).

This appears to be the first description of the call of this species. The stridulatory file is described by Nickle and Carlysle (1975), and the song of the congeneric species *M. modesta* is described by Nickle (1984).
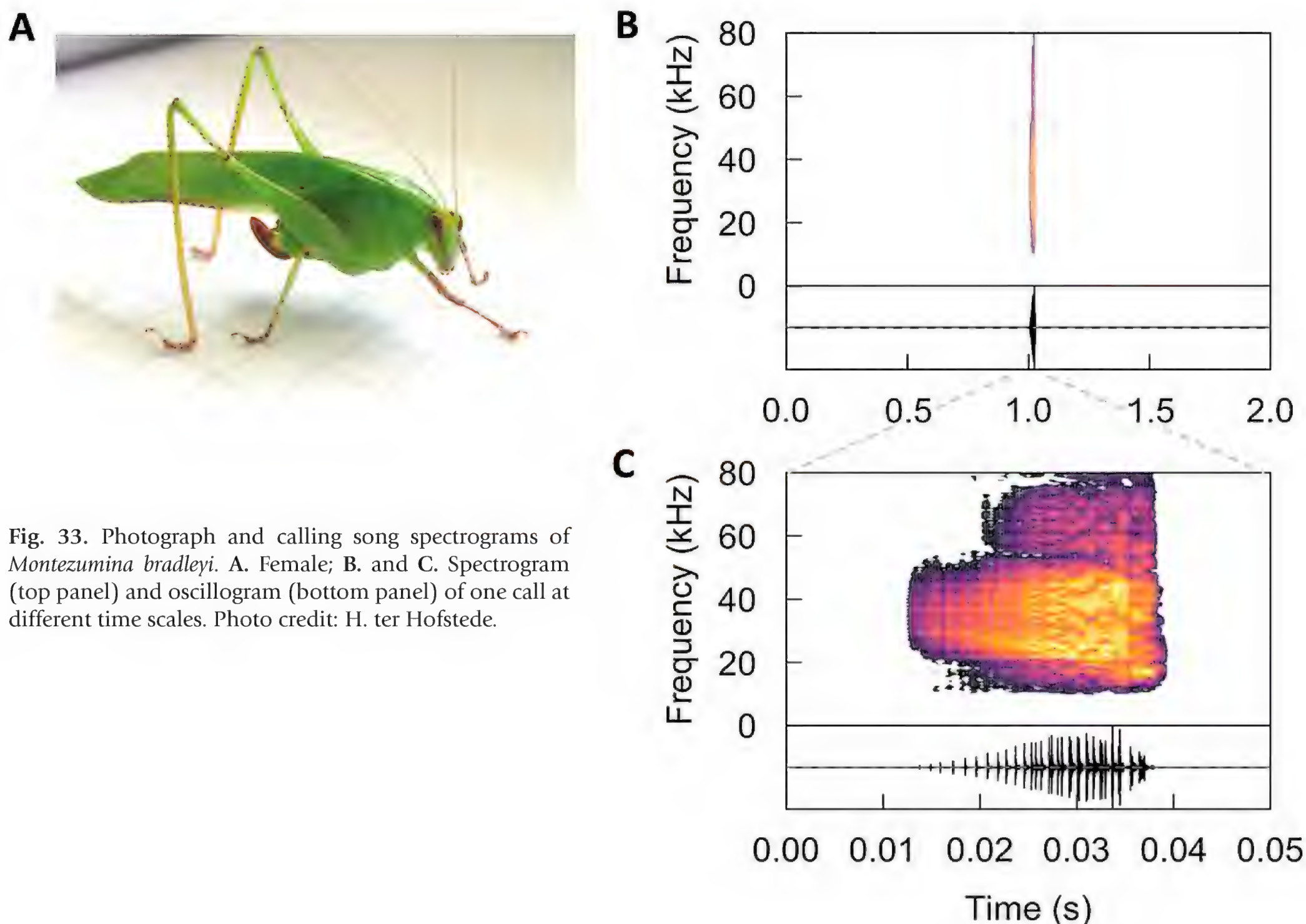
Fig. 33. Photograph and calling song spectrograms of *Montezumina bradleyi.* **A.** Female; **B.** and **C.** Spectrogram (top panel) and oscillogram (bottom panel) of one call at different time scales. Photo credit: H. ter Hofstede.

Orophus conspersus (Brunner von Wattenwyl, 1878)
Fig. 34 [MNHN-SO-2019-1574, -1575, -1576, -1577]

Orophus conspersus is a large (1.1 ± 0.13 g, n = 13) species with broad wings and is highly variable in color. Morphs range from bright green through tan, brown, and a deep reddish brown, a color most often seen in females (Fig. 34A, B). The tympana of this species are often white (Fig. 34B). This species is known from Guatemala, Nicaragua, Costa Rica, Panama, and Colombia (Cigliano et al. 2020).

The call consists of a series of 1–4 pulses (mean: 3; Fig. 34C, D) with a total call duration ranging from 9–96 ms and having a mean of ~70 ms (Table 1). The peak frequency of the entire call is ~11 kHz with a -20 dB frequency range spanning ~7–19 kHz, giving a bandwidth of ~12 kHz (Table 1). Pulse amplitudes either consistently increase or they increase and then decrease across the call (Fig. 34D).

Pulse durations and pulse periods vary slightly over the call (Table 28). The pulses in the call are all similar in their spectral properties (Table 28).

The calls of this species were previously described by Taliaferro et al. (1999).
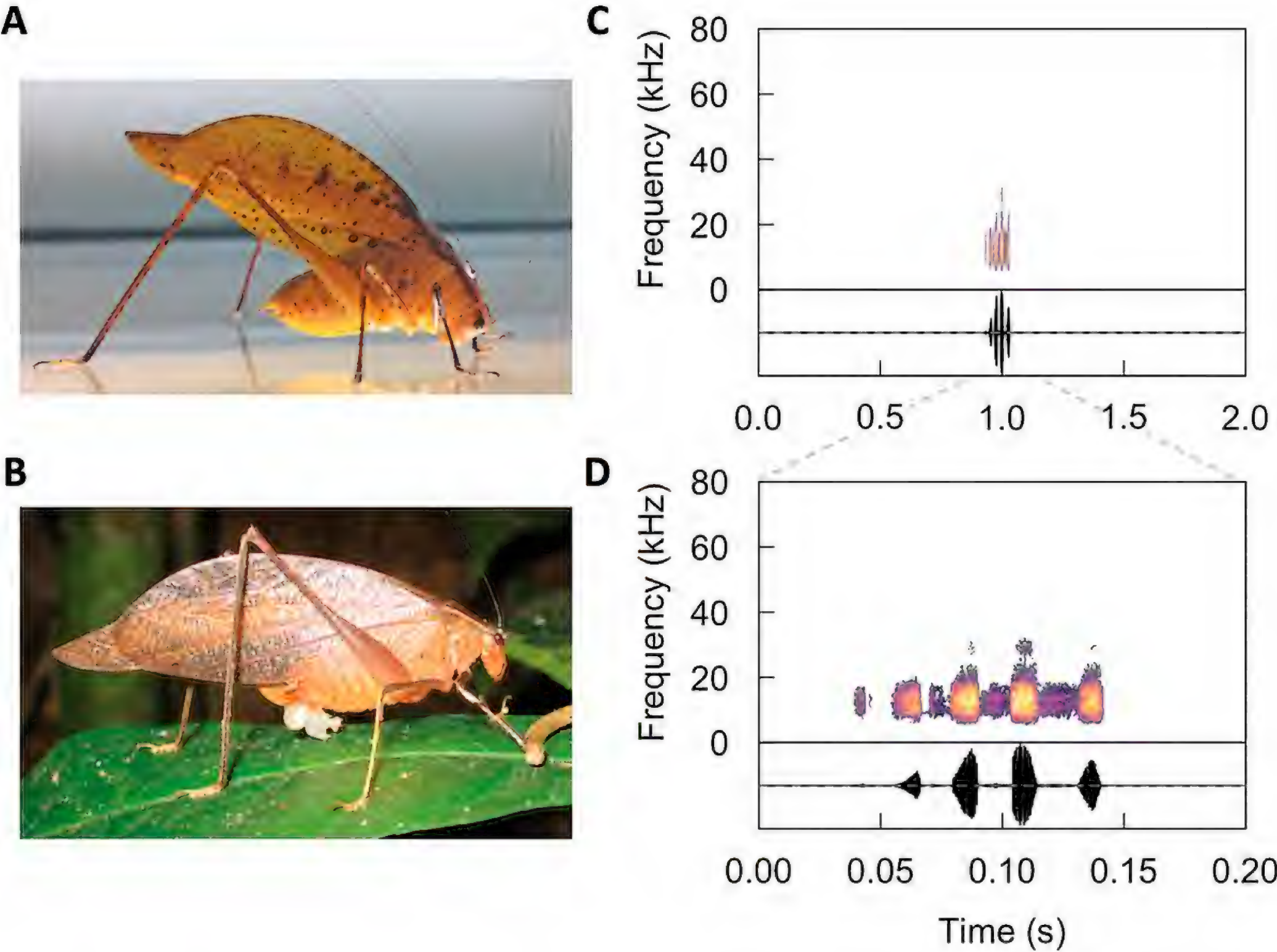
Fig. 34. Photographs and calling song spectrograms of *Orophus conspersus*. **A.** Male (photo credit: C. Wilson); **B.** Female with a spermatophore (photo credit: H. ter Hofstede); **C.** and **D.** Spectrogram (top panel) and oscillogram (bottom panel) of one call at different time scales.

Table 28. Call pulse parameters of *Orophus conspersus*. (4 individuals, 40 calls; mean ± SD); n = number of pulses measured.

Pulse Number (n)	Pulse Duration (ms)	Pulse Period (ms)	Peak Frequency (kHz)	Low Frequency (kHz)	High Frequency (kHz)	Bandwidth (kHz)
1 (40)	12.9 ± 5.3		11.2 ± 0.1	7.7 ± 0.6	18.4 ± 1.1	10.7 ± 1.4
2 (37)	13.5 ± 4.7	30.8 ± 8.3	11.1 ± 0.3	7.5 ± 0.4	18.9 ± 1.0	11.4 ± 1.2
3 (28)	11.1 ± 3.4	27.4 ± 1.2	11.3 ± 1.0	7.5 ± 0.5	18.4 ± 0.1	10.8 ± 0.5
4 (18)	8.4 ± 0.1	27.1 ± 3.8	11.7 ± 0.6	7.4 ± 0.4	18.2 ± 0.3	10.8 ± 0.3

Philophyllia ingens **Hebard, 1933**
Fig. 35 [MNHN-SO-2019-1578, -1579, -1580, -1581, -1582, -1583, -1584, -1585, -1586]

Philophyllia ingens is a very large (3.43 ± 0.65 g, n = 38), green katydid with broad wings, yellow spots on the tegminal margin, and white stripes on the face that extend from the eye to the base of the mandible (Fig. 35A, B). This species is known from Nicaragua, Costa Rica, Panama, and Colombia (Cigliano et al. 2020).

The call consists of a single pulse with a duration ∼6 ms (Table 1; Fig. 35C, D). The peak frequency of the call is ∼11 kHz with a -20 dB range spanning 9–13 kHz, giving a narrow bandwidth of ∼4 kHz. The call usually has a very strong harmonic structure. The fundamental frequency of the call is 5 kHz, with the first harmonic (10–11 kHz) being of a higher amplitude than the fundamental and the other harmonics (Fig. 35D).

The calls of this species were previously described by Falk et al. (2015).
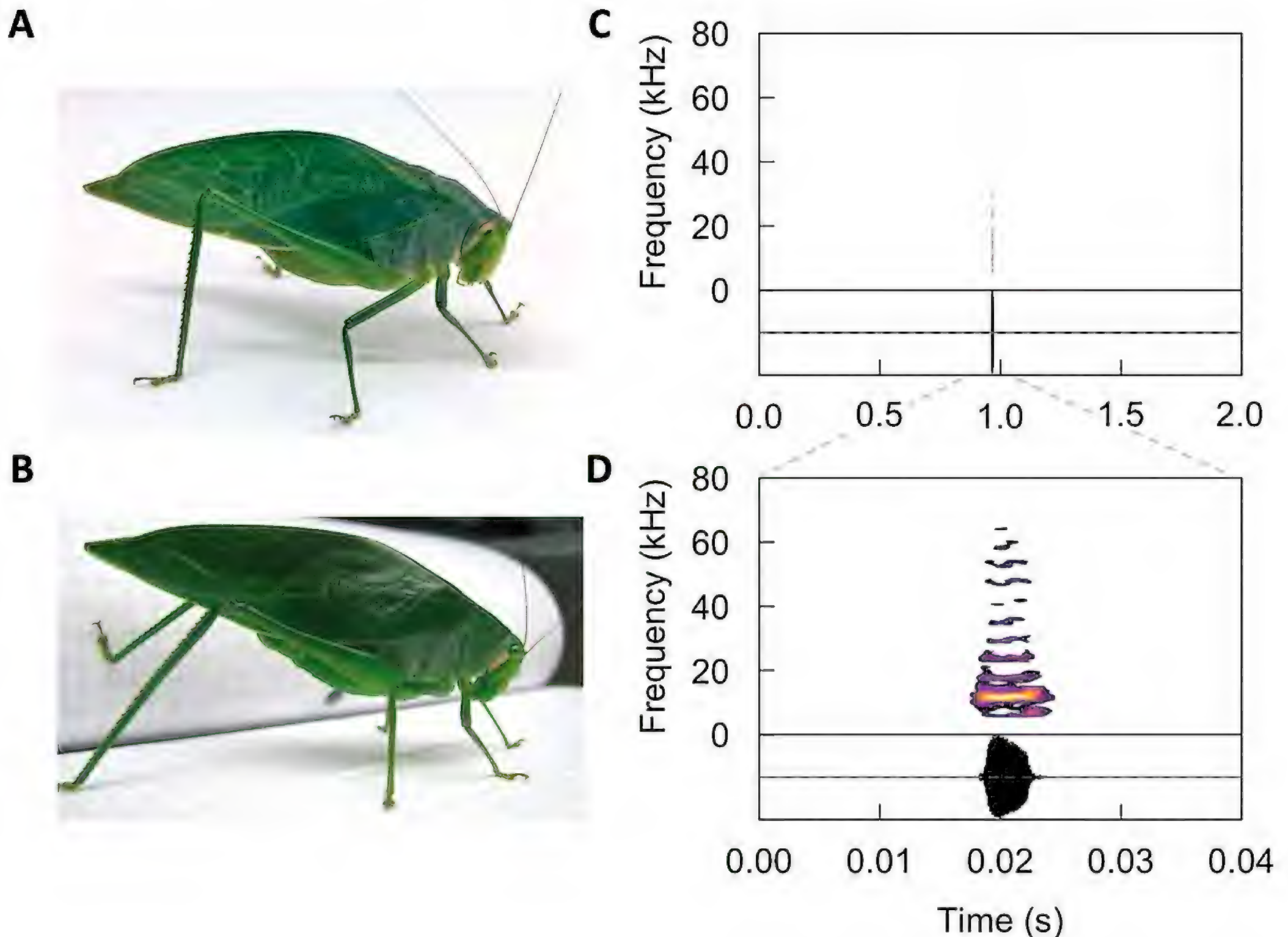
Fig. 35. Photographs and calling song spectrograms of *Philophyllia ingens*. **A.** Male (photo credit: C. Wilson); **B.** Female (photo credit: H. ter Hofstede); **C.** and **D.** Spectrogram (top panel) and oscillogram (bottom panel) of one call at different time scales.

Phylloptera dimidiata **Brunner von Wattenwyl, 1878**
Fig. 36 [MNHN-SO-2019-1587, -1588, -1589, -1590, -1591, -1592, -1593, -1594, -1595, -1788, -1789, -1790]

Phylloptera dimidiata is a mid-sized (0.54 ± 0.08 g, n = 115), green katydid with broad wings, pink legs, and a black saddle on the posterior third of the pronotum (Fig. 36A, B). This species is known from Costa Rica, Panama, and Colombia (Cigliano et al. 2020).

The call consists of a series of 5–13 very short pulses (mean: 8; Fig. 36C, D) with a total call duration ranging from 11–29 ms and having a mean of ~21 ms (Table 1). The peak frequency of the entire call is ~16 kHz with a -20 dB frequency range spanning ~10–25 kHz, giving a bandwidth of ~15 kHz (Table 1). Pulse amplitudes typically increase and then decrease across the call (Fig. 36D).

Pulse durations increase across the call, whereas pulse periods decrease slightly across the call (Table 29). The peak frequency of each pulse decreases across the call (Table 29). The low and high frequencies of each pulse also decrease slightly across the call (Table 29).

The calls of this species were previously described by Symes et al. (2016).
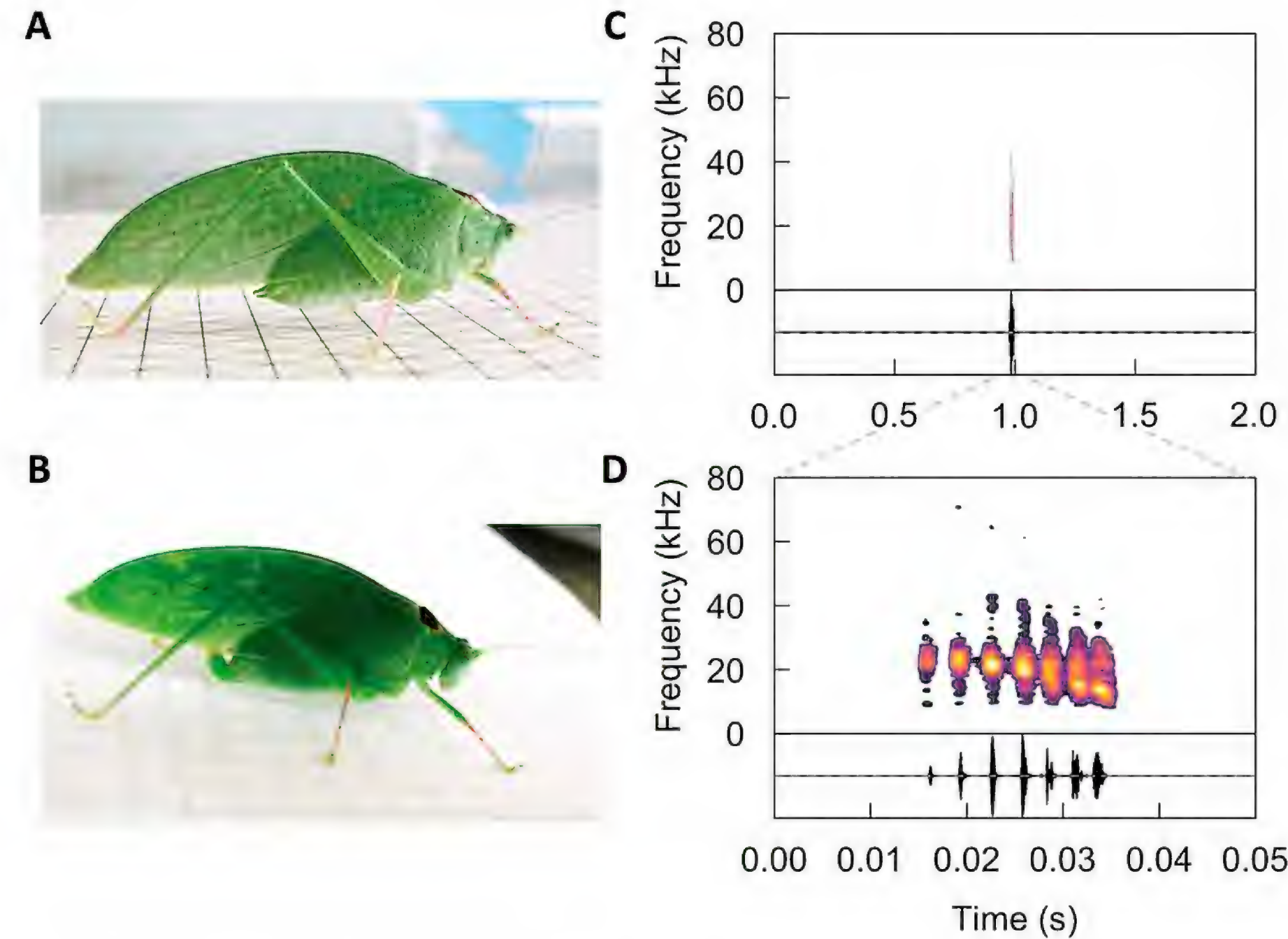
Fig. 36. Photographs and calling song spectrograms of *Phylloptera dimidiata*. **A.** Male (photo credit: C. Wilson); **B.** Female (photo credit: H. ter Hofstede); **C.** and **D.** Spectrogram (top panel) and oscillogram (bottom panel) of one call at different time scales.

Table 29. Call pulse parameters of *Phylloptera dimidiata* (12 individuals, 204 calls; mean ± SD); n = number of pulses measured.

Pulse Number (n)	Pulse Duration (ms)	Pulse Period (ms)	Peak Frequency (kHz)	Low Frequency (kHz)	High Frequency (kHz)	Bandwidth (kHz)
1 (204)	0.4 ± 0.1		20.5 ± 1.3	15.4 ± 2.0	26.4 ± 0.9	9.9 ± 2.2
2 (204)	0.5 ± 0.1	3.3 ± 0.6	20.2 ± 1.4	15.8 ± 1.7	25.8 ± 0.8	9.9 ± 1.6
3 (204)	0.6 ± 0.1	3.3 ± 0.6	18.9 ± 1.4	15.2 ± 1.3	24.9 ± 1.0	9.7 ± 1.0
4 (204)	0.8 ± 0.1	3.1 ± 0.6	17.2 ± 1.4	13.7 ± 1.5	24.2 ± 1.2	10.4 ± 1.7
5 (204)	0.9 ± 0.2	2.9 ± 0.5	15.5 ± 1.4	12.3 ± 1.5	23.1 ± 1.2	10.8 ± 1.7
6 (200)	0.9 ± 0.2	2.8 ± 0.5	14.1 ± 1.6	11.2 ± 1.4	23.0 ± 2.2	11.8 ± 2.4
7 (163)	0.9 ± 0.2	2.6 ± 0.5	13.1 ± 1.6	10.3 ± 1.4	23.2 ± 2.4	12.9 ± 2.9
8 (83)	0.8 ± 0.1	2.3 ± 0.4	12.4 ± 1.5	9.5 ± 1.0	23.3 ± 2.1	13.9 ± 2.3
9 (26)	0.9 ± 0.5	2.0 ± 0.4	12.9 ± 1.6	9.2 ± 0.9	23.6 ± 1.5	14.4 ± 1.5
10 (13)	0.8 ± 0.2	2.1 ± 0.5	13.8 ± 1.1	9.2 ± 1.9	22.7 ± 1.2	13.5 ± 0.9
11 (8)	0.8 ± 0.0	1.6 ± 0.2	13.2 ± 0.8	9.2 ± 1.7	22.8 ± 2.7	13.6 ± 0.9
12 (6)	0.9 ± 0.3	2.0 ± 0.2	12.6 ± 0.2	8.6 ± 2.8	23.5 ± 0.2	15.0 ± 2.5

Phylloptera quinquemaculata **Bruner, 1915**
Fig. 37 [MNHN-SO-2019-1791, -1792, -1793]

Phylloptera quinquemaculata is a mid-sized (0.79 ± 0.25 g, n = 8), green katydid with pink legs that are strongly banded with black and five spots (or clusters of spots) on the tegmina (Fig. 37A, B). This species has not been previously recorded from Panama. It is known from Colombia and central Brazil (Cigliano et al. 2020).

The call consists of a series of 6–11 pulses (mean: 9; Fig. 37C, D) produced in two groups, with a total call duration ranging from 46–60 ms and having a mean of ~53 ms (Table 1). The peak fre-

quency of the entire call is ~12 kHz with a -20 dB frequency range spanning ~9–20 kHz, giving a bandwidth of ~11 kHz (Table 1). Pulse amplitudes typically increase and then decrease across each pulse group (Fig. 37D).

The call looks very similar to two short *Phylloptera dimidiata* calls produced ~24 ms apart (Table 30). Pulse durations and pulse periods are consistent across the call (Table 30). The peak frequency of each pulse decreases across each pulse group (Table 30). The low and high frequencies of each pulse also decrease slightly across the call (Table 30).

This appears to be the first description of the call of this species.
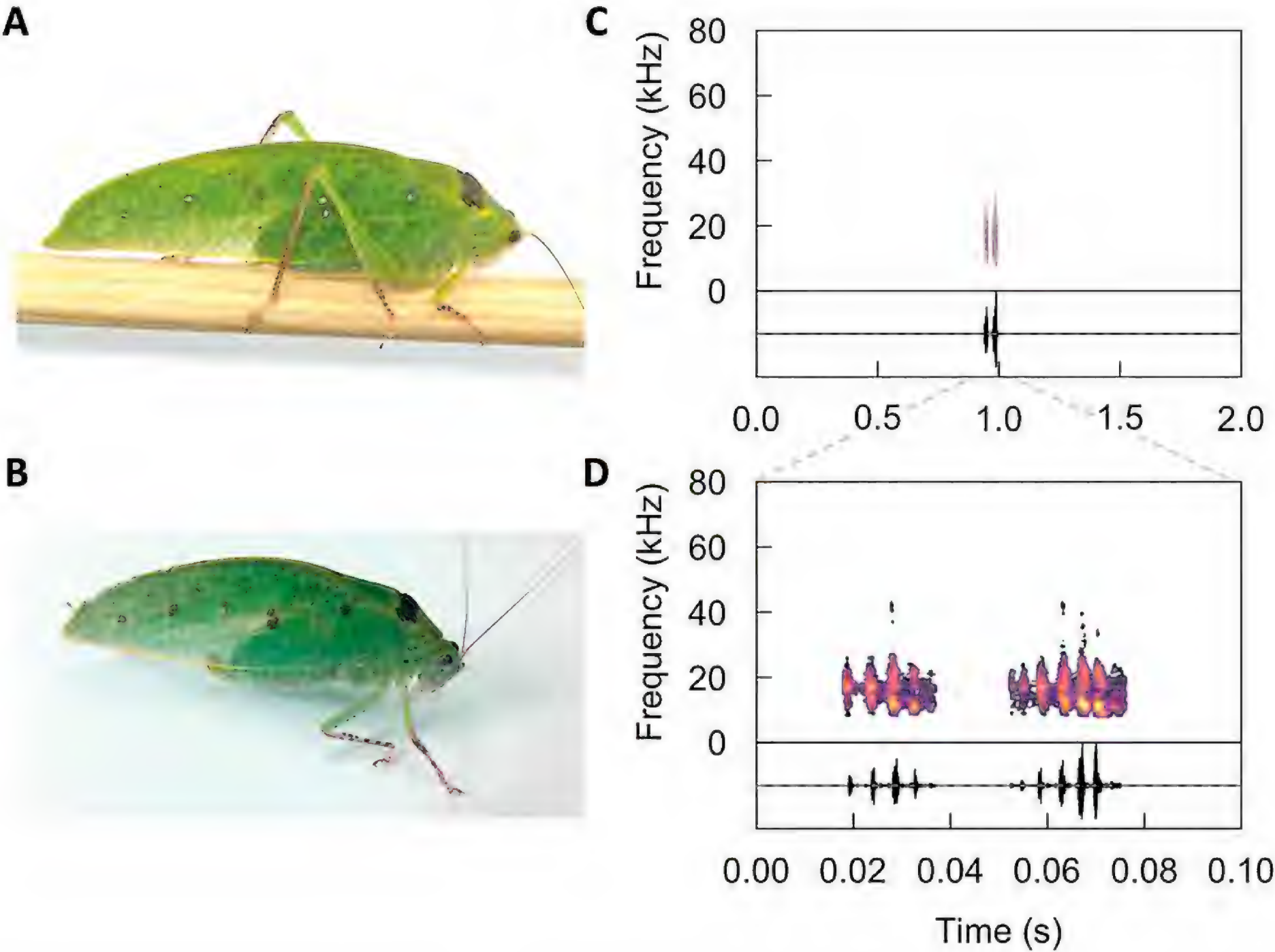
Fig. 37. Photographs and calling song spectrograms of *Phylloptera quinquemaculata*. **A.** Male (photo credit: C. Wilson); **B.** Female (photo credit: H. ter Hofstede); **C.** and **D.** Spectrogram (top panel) and oscillogram (bottom panel) of one call at different time scales.

Table 30. Call pulse parameters of *Phylloptera quinquemaculata* (3 individuals, 15 calls; mean ± SD); n = number of pulses measured.

Pulse Group	Pulse Number (n)	Pulse Duration (ms)	Pulse Period (ms)	Peak Frequency (kHz)	Low Frequency (kHz)	High Frequency (kHz)	Bandwidth (kHz)
1	1 (15)	0.9 ± 0.2		15.5 ± 1.0	12.3 ± 0.4	19.0 ± 0.7	6.7 ± 0.3
1	2 (15)	1.1 ± 0.1	4.3 ± 0.6	14.4 ± 1.1	10.8 ± 0.6	19.4 ± 3.1	8.6 ± 3.5
1	3 (13)	1.4 ± 0.2	4.1 ± 0.4	12.2 ± 0.6	10.2 ± 0.4	16.2 ± 1.5	5.9 ± 1.2
1	4 (12)	1.2 ± 0.4	3.8 ± 0.4	11.3 ± 0.4	9.5 ± 0.3	14.1 ± 0.7	4.6 ± 0.6
1	5 (5)	1.3 ± 0.3	3.8 ± 1.0	11.5 ± 0.4	8.5 ± 0.2	15.0 ± 0.5	6.5 ± 0.3
2	1 (15)	0.7 ± 0.1	23.5 ± 2.4	15.8 ± 1.0	12.4 ± 1.5	19.3 ± 1.0	6.8 ± 1.0
2	2 (15)	1.1 ± 0.1	3.7 ± 0.3	15.3 ± 1.2	11.3 ± 1.3	19.4 ± 1.7	8.1 ± 2.5
2	3 (15)	1.4 ± 0.2	4.1 ± 0.5	12.9 ± 0.7	10.3 ± 0.9	18.5 ± 2.8	8.2 ± 3.6
2	4 (15)	1.4 ± 0.3	3.7 ± 0.4	11.7 ± 0.5	9.6 ± 0.5	14.7 ± 1.2	5.0 ± 0.8
2	5 (13)	1.4 ± 0.3	3.3 ± 0.2	11.1 ± 0.1	8.4 ± 0.3	14.8 ± 2.0	6.4 ± 2.1
2	6 (6)	1.2 ± 0.4	3.8 ± 1.3	10.4 ± 0.3	8.4 ± 0.8	15.1 ± 0.7	6.8 ± 0.1

Pycnopalpa bicordata (Saint-Fargeau & Serville, 1825)
Fig. 38 [MNHN-SO-2019-1797, -1798, -1799]

Pycnopalpa bicordata is a very small (0.12 ± 0.02 g, n = 16) katydid with green and brown coloration, white tarsi, transparent windows in the wings that look like dead patches in a leaf, and two heart-shaped green markings on the pronotum (Fig. 38A, B). This species is known from southern Mexico, Honduras, Costa Rica, Panama, and Colombia (Cigliano et al. 2020).

The call consists of a series of 4–6 pulses (mean: 5; Fig. 38C, D) with a total call duration ranging from 25–47 ms and having a mean of ~33 ms (Table 1). The peak frequency of the entire call is ~26 kHz with a -20 dB frequency range spanning ~23–32 kHz, giving a bandwidth of ~9 kHz (Table 1). Pulse amplitudes either consistently increase or they increase and then decrease across the call (Fig. 38D).

Pulse durations and pulse periods are quite consistent across the call (Table 31). The pulses in the call are all similar in their spectral properties (Table 31). Pulses often have short silent gaps within them, such that they appear like two very short pulses produced in rapid succession (Fig. 38D).

The calls of this species were previously described by Falk et al. (2015).
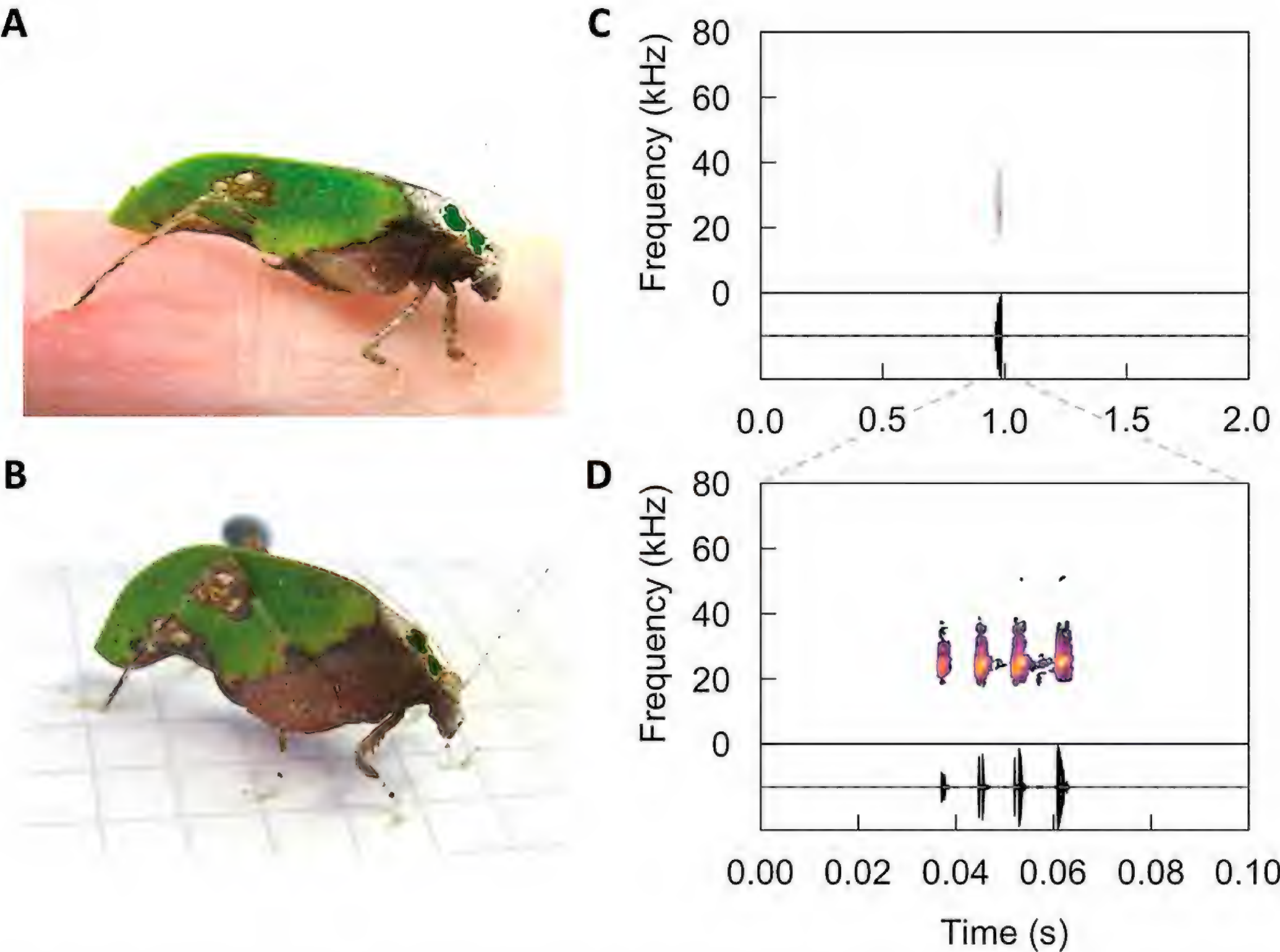
Fig. 38. Photographs and calling song spectrograms of *Pycnopalpa bicordata*. **A.** Male; **B.** Female; **C.** and **D.** Spectrogram (top panel) and oscillogram (bottom panel) of one call at different time scales. Photo credit: H. ter Hofstede.

Table 31. Call pulse parameters of *Pycnopalpa bicordata* (3 individuals, 14 calls; mean ± SD); n = number of pulses measured.

Pulse Number (n)	Pulse Duration (ms)	Pulse Period (ms)	Peak Frequency (kHz)	Low Frequency (kHz)	High Frequency (kHz)	Bandwidth (kHz)
1 (14)	1.3 ± 0.2		28.2 ± 3.6	23.1 ± 1.9	34.7 ± 5.3	11.6 ± 3.5
2 (14)	0.9 ± 0.4	7.5 ± 0.3	26.5 ± 1.6	23.1 ± 1.1	31.9 ± 3.4	8.8 ± 2.7
3 (14)	1.1 ± 0.4	7.5 ± 0.6	26.1 ± 1.2	23.8 ± 1.0	30.5 ± 2.8	6.7 ± 2.2
4 (14)	1.5 ± 0.7	7.9 ± 0.6	26.2 ± 0.8	23.3 ± 1.3	30.3 ± 1.8	7.0 ± 0.6
5 (10)	1.8 ± 0.1	7.8 ± 1.8	26.3 ± 0.6	23.4 ± 0.7	30.5 ± 1.0	7.0 ± 1.7

Steirodon stalii **(Brunner von Wattenwyl, 1878)**
Fig. 39 [MNHN-SO-2019-1803, -1804, -1805, -1806, -1807,
-1808, -1809, -1810, -1811, -1812, -1813]

Steirodon stalii is a very large (4.16 ± 0.49 g, n = 22), green katydid with yellow-tipped ridges along the edge of the pronotum (Fig. 39A). This species is known from Nicaragua, Costa Rica, Panama, Colombia, and Brazil (Nickle 1992, Cigliano et al. 2020).

The call consists of a series of three pulses (Fig. 39B, C) with a total call duration ranging from 187–247 ms and having a mean of ~209 ms (Table 1). The peak frequency of the entire call is ~19 kHz with a -20 dB frequency range spanning ~13–24 kHz, giving a bandwidth of ~11 kHz (Table 1). Pulse amplitudes usually increase across the call (Fig. 39C).

Pulse durations and pulse periods are quite consistent across the call (Table 32). The pulses in the call are all similar in their spectral properties (Table 32).

This appears to be the first description of the call of this species.
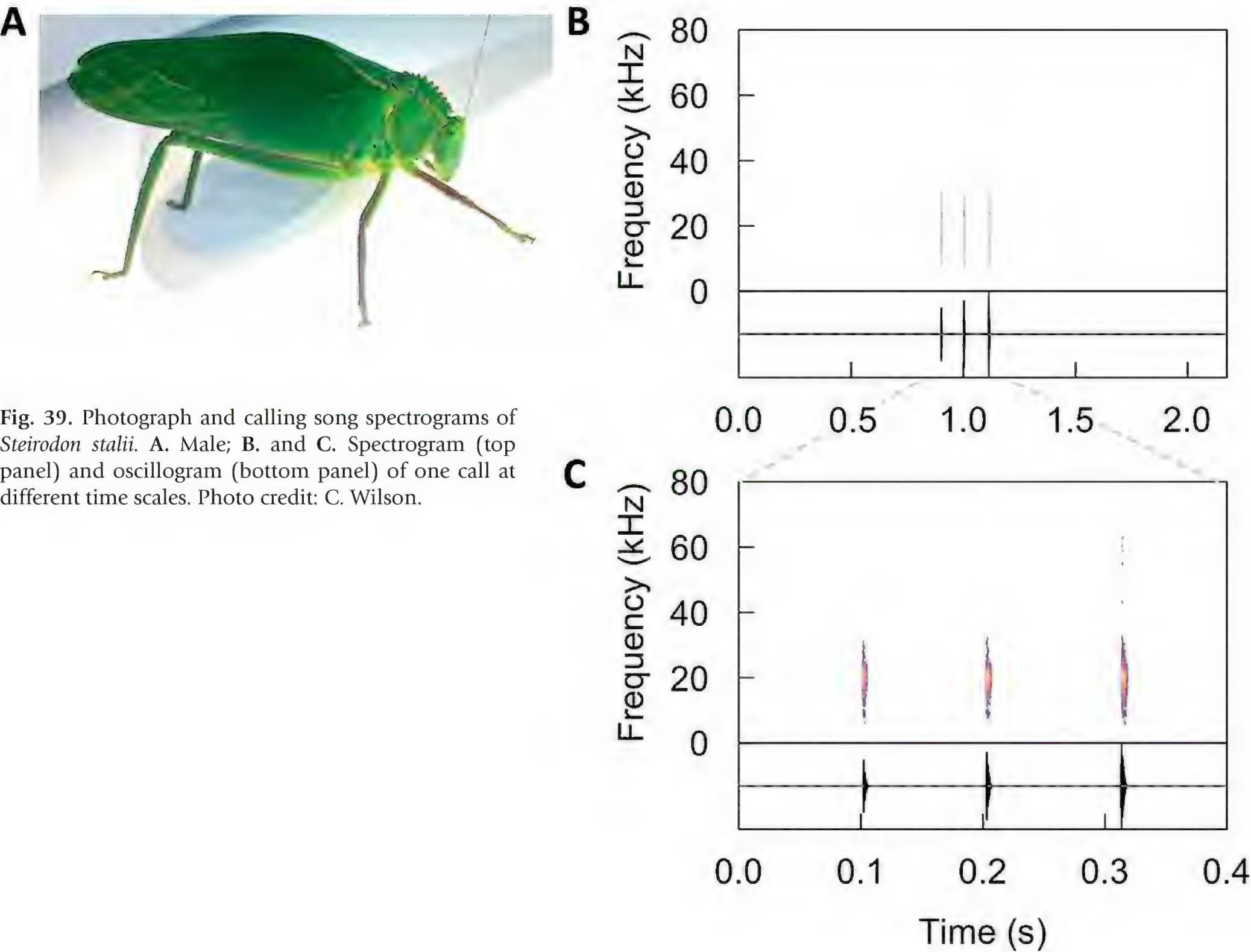
Fig. 39. Photograph and calling song spectrograms of *Steirodon stalii.* **A.** Male; **B.** and **C.** Spectrogram (top panel) and oscillogram (bottom panel) of one call at different time scales. Photo credit: C. Wilson.

Table 32. Call pulse parameters of *Steirodon stalii* (10 individuals, 92 calls; mean ± SD); n = number of pulses measured.

Pulse Number (n)	Pulse Duration (ms)	Pulse Period (ms)	Peak Frequency (kHz)	Low Frequency (kHz)	High Frequency (kHz)	Bandwidth (kHz)
1 (92)	4.8 ± 2.3		19.0 ± 1.5	13.6 ± 1.2	24.2 ± 1.0	10.6 ± 1.5
2 (92)	4.8 ± 2.0	94.5 ± 7.6	18.9 ± 1.1	13.5 ± 1.0	24.3 ± 1.1	10.8 ± 1.6
3 (92)	5.6 ± 2.3	107.6 ± 7.8	18.7 ± 1.7	13.2 ± 1.0	24.4 ± 1.3	11.2 ± 1.7

Viadana brunneri **Cadena-Castañeda, 2015**
Fig. 40 [MNHN-SO-2019-1823, -1824, -1825, -1826, -1827,
-1828, -1829, -1830, -1831, -1832, -1833]

Viadana brunneri is a small (0.38 ± 0.07 g, n = 70) and delicate green katydid with broad wings that give a strong impression of a single new leaf (Fig. 40A). This species was described by Gorochov and Cadena-Castañeda (2015), and they note that the species identified as *V. zetterstedti* in Panama by Hebard (1927, 1933) and Nickle (1992) corresponds with this species. This species is known from Panama and Colombia (Cigliano et al. 2020).

The call consists of a series of 2 pulses (Fig. 40B, C) with a total call duration ranging from 4–10 ms and having a mean of 8.6 ms (Table 1). The peak frequency of the entire call is ~16 kHz with a -20 dB frequency range spanning ~15–19 kHz, giving a bandwidth of ~4 kHz (Table 1). The second pulse is usually greater in amplitude than the first pulse (Fig. 40C).

The two pulses in the call are similar in their temporal and spectral properties (Table 33).

The calls of this species were previously described by Falk et al. (2015) and Symes et al. (2016) (identified as *V. zetterstedti* in these papers).
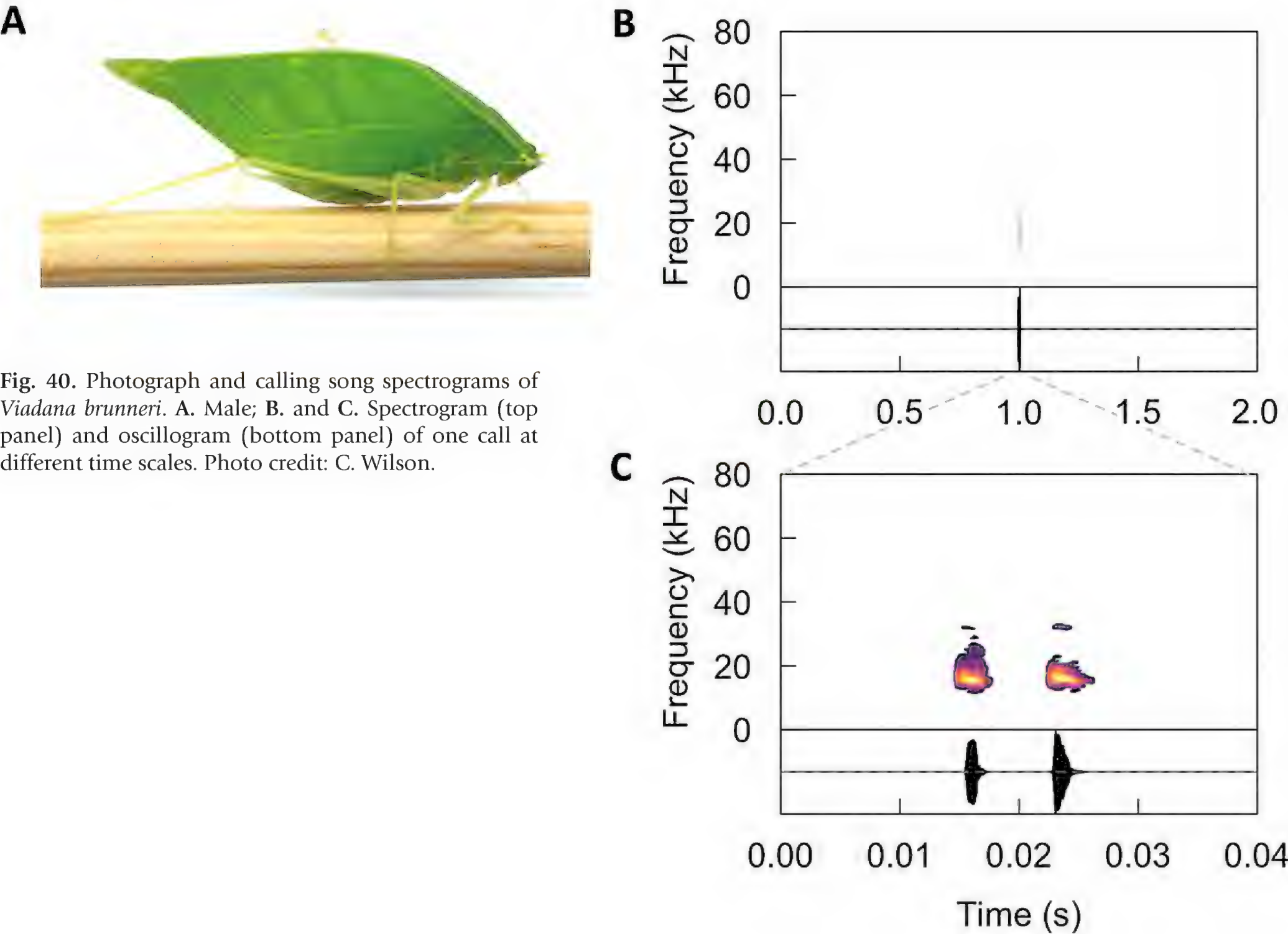
Fig. 40. Photograph and calling song spectrograms of *Viadana brunneri*. **A.** Male; **B.** and **C.** Spectrogram (top panel) and oscillogram (bottom panel) of one call at different time scales. Photo credit: C. Wilson.

Table 33. Call pulse parameters of *Viadana brunneri* (11 individuals, 195 calls; mean ± SD); n = number of pulses measured.

Pulse Number (n)	Pulse Duration (ms)	Pulse Period (ms)	Peak Frequency (kHz)	Low Frequency (kHz)	High Frequency (kHz)	Bandwidth (kHz)
1 (195)	1.3 ± 0.2		16.2 ± 0.5	14.6 ± 0.5	18.3 ± 0.8	3.7 ± 0.5
2 (195)	1.6 ± 0.2	6.9 ± 0.5	16.2 ± 0.5	14.9 ± 0.5	18.3 ± 0.7	3.4 ± 0.6

Phaneropterinae gen. "Waxy sp."
Fig. 41

Phaneropterinae gen. "Waxy sp." is a mid-sized (0.73 ± 0.18 g, n = 73) katydid with very rounded and tough tegmina that have a waxy surface (Fig. 41A, B). We believe that this might be an undescribed species and provide the temporary name "Waxy sp." due to the unusually waxy feel of the wings. The calls recorded from these individuals are all the same and can be readily distinguished from the other katydids we recorded in Panama.

The call consists of a series of 6–8 pulses (mean: 6.5; Fig. 41C, D) produced in two groups with a total call duration ranging from 65–73 ms and having a mean of ~70 ms (Table 1). The peak frequency of the entire call is ~12 kHz with a -20 dB frequency range spanning ~10–18 kHz, giving a bandwidth of ~8 kHz (Table 1). Pulse amplitudes typically increase across each pulse group (Fig. 41D), but they can also be constant or decrease in amplitude.

Pulse durations increase within each pulse group, whereas pulse periods within pulse groups are similar (Table 34). The peak frequency of each pulse decreases within each pulse group (Table 34). The low and high frequencies of each pulse also decrease slightly within each pulse group, with a bandwidth of ~5–7 kHz (Table 34).
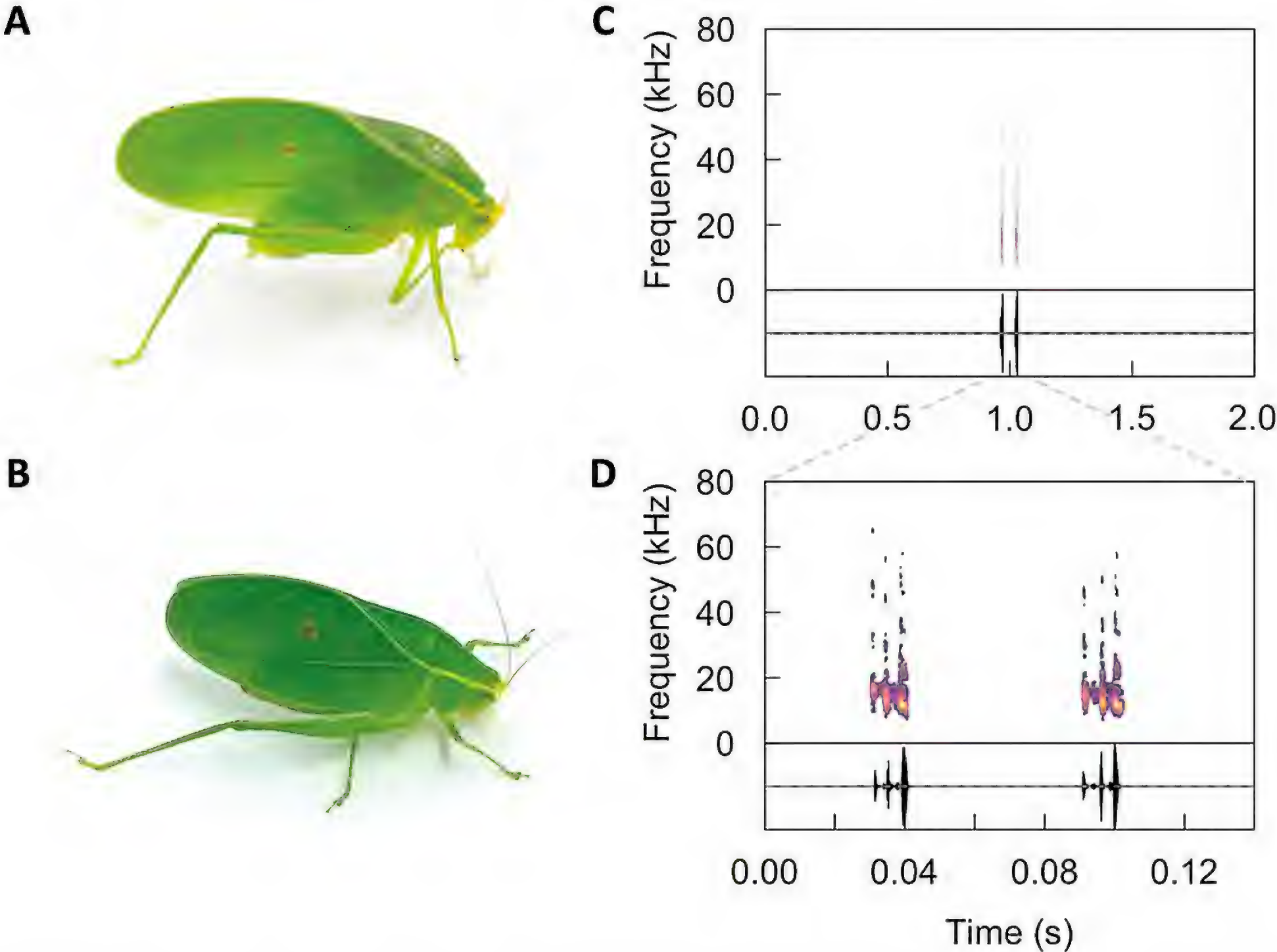
Fig. 41. Photographs and calling song spectrograms of "Waxy" sp. **A.** Male; **B.** Female; **C.** and **D.** Spectrogram (top panel) and oscillogram (bottom panel) of one call at different time scales. Photo credit: C. Wilson.

Table 34. Call pulse parameters of "Waxy sp." (3 individuals, 13 calls; mean ± SD); n = number of pulses measured.

Pulse Group	Pulse Number (n)	Pulse Duration (ms)	Pulse Period (ms)	Peak Frequency (kHz)	Low Frequency (kHz)	High Frequency (kHz)	Bandwidth (kHz)
1	1 (13)	0.7 ± 0.2		15.5 ± 0.3	12.5 ± 0.8	18.0 ± 0.5	5.5 ± 0.6
1	2 (13)	0.9 ± 0.2	4.5 ± 0.4	13.3 ± 0.2	10.6 ± 1.0	17.0 ± 0.4	6.4 ± 1.2
1	3 (13)	1.6 ± 0.1	4.0 ± 0.4	11.5 ± 0.3	10.2 ± 0.6	15.3 ± 0.7	5.1 ± 1.2
2	1 (13)	0.7 ± 0.2	47.4 ± 3.2	15.1 ± 0.3	11.6 ± 0.8	18.0 ± 0.4	6.4 ± 1.0
2	2 (13)	1.1 ± 0.5	5.1 ± 0.1	12.9 ± 0.5	10.6 ± 0.9	16.7 ± 0.9	6.1 ± 1.7
2	3 (13)	1.6 ± 0.1	4.6 ± 0.2	11.5 ± 0.5	10.3 ± 0.4	15.3 ± 0.6	5.0 ± 0.9

Pseudophyllinae

Acanthodis curvidens (Stål, 1875)
Fig. 42 [MNHN-SO-2019-209, -210, -211]

Acanthodis curvidens is a very large (2.98 ± 0.2 g, n = 6), brown and green mottled katydid with a blue and white face, purple markings on the ventral surface, and prominent hooked spines on the hind limbs (Fig. 42A, B). It is very well-camouflaged when resting on lichen-covered bark. This species is known from Panama and Colombia (Cigliano et al. 2020).

The call begins with a long, low amplitude sound, likely a wing opening sound, followed by 3–4 short pulses and ends with a longer, higher amplitude pulse (Table 35; Fig. 42C, D). Wing-opening sounds are often also seen before each short pulse (Fig. 42D). The total call duration, not including the first wing-opening sound, ranges from 65–73 ms and has a mean of 64 ms (Table 1). The peak frequency of the call is ~16 kHz with a -20 dB range spanning ~10–22 kHz, giving a bandwidth of ~12 kHz (Table 1).

The peak frequency and the amplitude of the pulses increase across the call (Table 35). The initial wing-opening sound is long, and the short pulses that follow the wing-opening sound tend to increase in both duration and peak frequency (Table 35). The final pulse is longer, greater in amplitude, and has a higher peak frequency than the preceding pulses. The pulse periods of the call are fairly consistent (Table 35).

The calls of this species were previously described by Belwood (1988a) and Falk et al. (2015). In addition to acoustic signals, both males and females produce vibrational signals (described in Belwood 1988a).
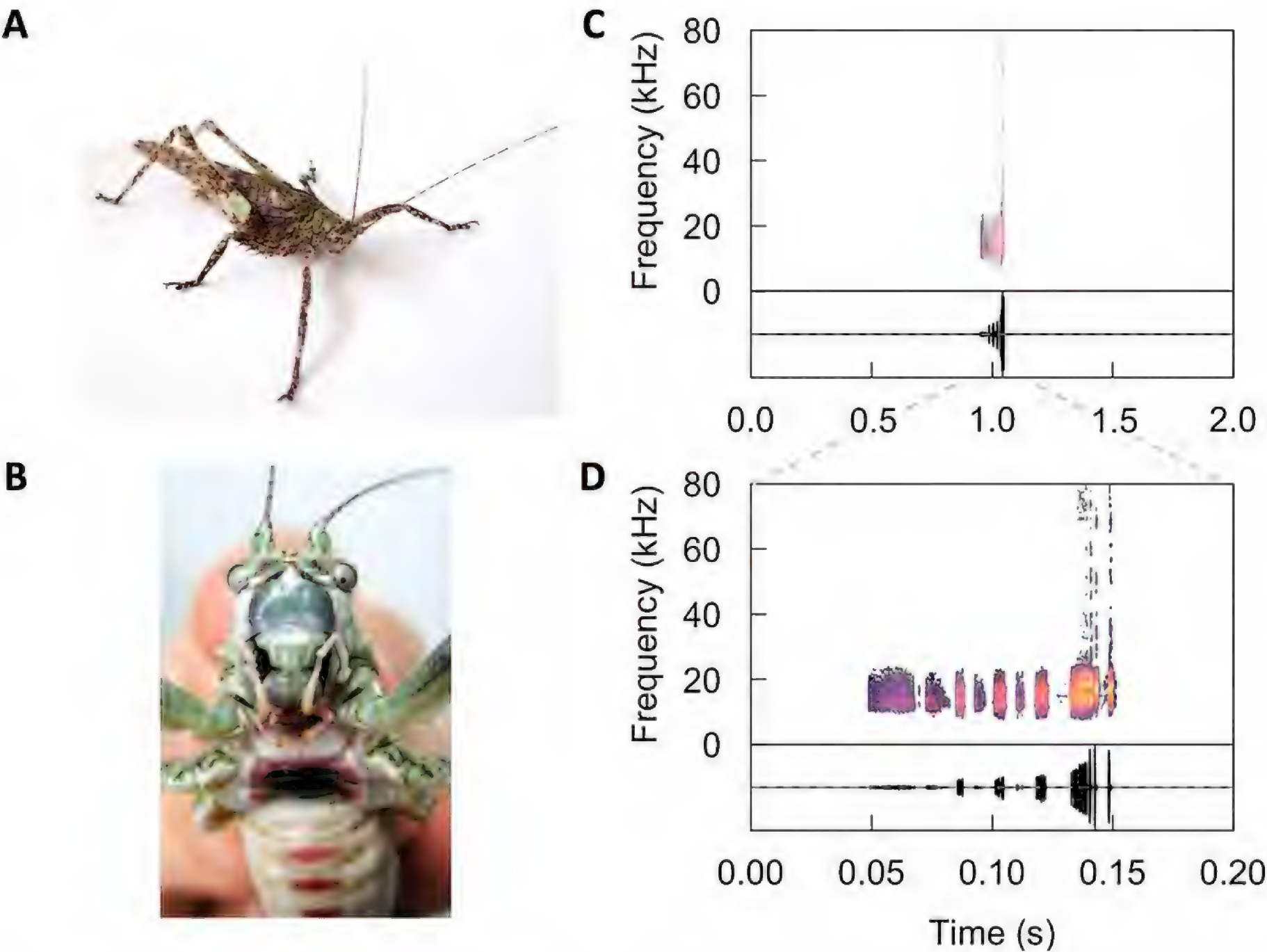
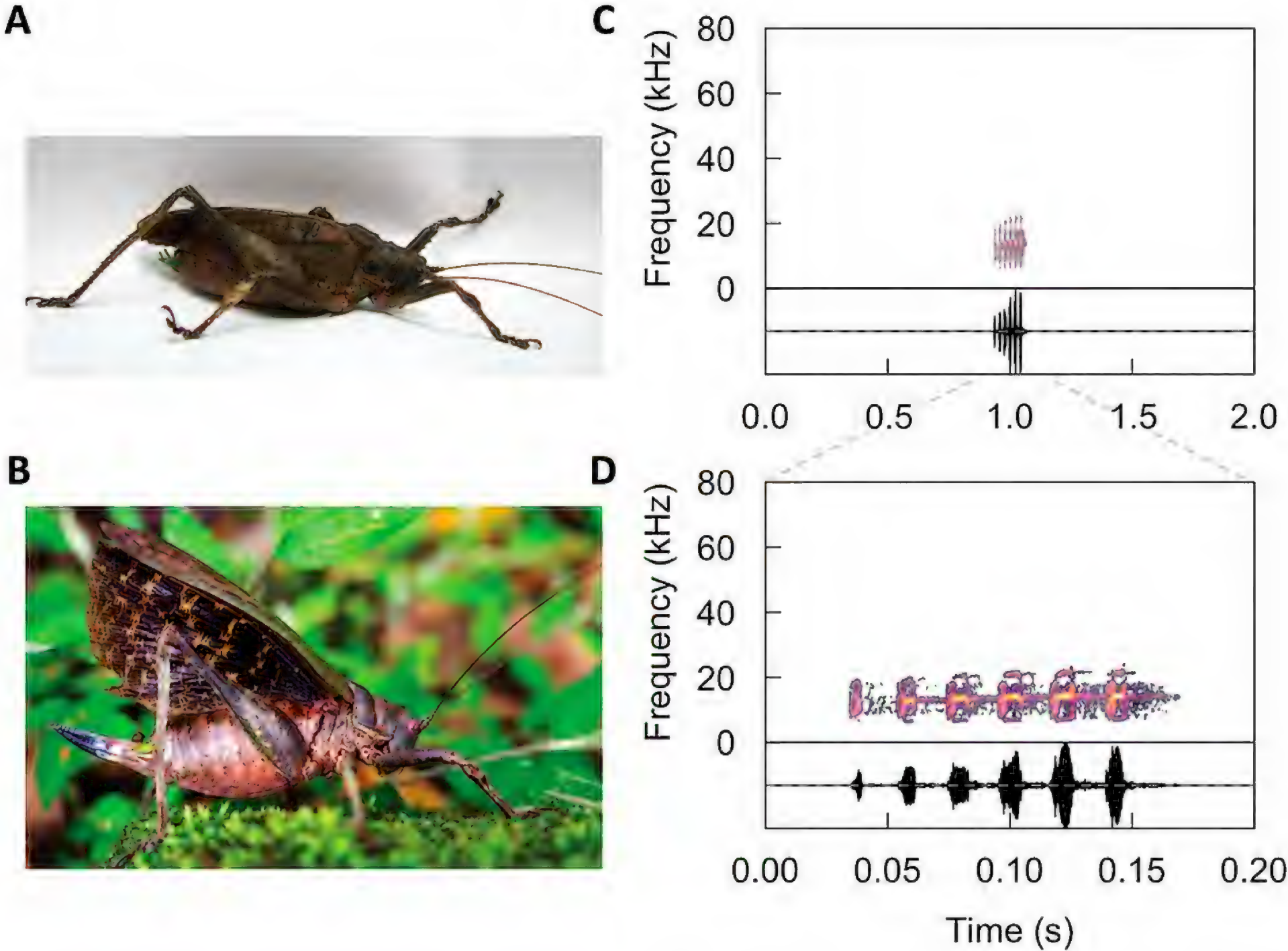**Fig. 42.** Photographs and calling song spectrograms of *Acanthodis curvidens*. **A.** Male (photo credit: T. Robillard); **B.** Face (photo credit: H. ter Hofstede); **C.** and **D.** Spectrogram (top panel) and oscillogram (bottom panel) of one call at different time scales.

Table 35. Call pulse parameters of *Acanthodis curvidens* (3 individuals, 38 calls; mean ± SD); WO: wing-opening sound at start of each call; LP: last pulse, which is either pulse 4 or 5; n = number of pulses measured.

Pulse Number (n)	Pulse Duration (ms)	Pulse Period (ms)	Peak Frequency (kHz)	Low Frequency (kHz)	High Frequency (kHz)	Bandwidth (kHz)
WO (38)	19.3 ± 0.7		11.7 ± 0.8	8.8 ± 1.1	20.2 ± 1.0	11.4 ± 0.5
1 (38)	4.0 ± 1.5	34.4 ± 4.5	12.6 ± 0.1	8.8 ± 0.5	19.7 ± 1.3	10.9 ± 0.9
2 (38)	4.8 ± 1.8	15.0 ± 1.5	12.7 ± 0.2	9.2 ± 0.2	20.0 ± 0.8	10.7 ± 0.6
3 (38)	5.2 ± 2.0	15.6 ± 0.8	13.6 ± 0.9	9.3 ± 0.1	20.2 ± 0.9	10.9 ± 0.7
4 (15)	5.9 ± 0.2	16.0 ± 1.8	14.7 ± 0.6	9.6 ± 0.1	19.6 ± 2.3	10.0 ± 2.4
LP (38)	12.9 ± 4.3	13.9 ± 0.7	16.1 ± 0.9	11.2 ± 1.4	20.2 ± 2.0	8.9 ± 2.8

Balboana tibialis (Brunner von Wattenwyl, 1895)
Fig. 43 [MNHN-SO-2019-298, -299, -300, -301]

Balboana tibialis is a very large (4.76 ± 0.75 g, n = 6) and robust dark brown katydid with black patches at the base of the forewings and bright green male cerci (Fig. 43A, B). This species is known from Nicaragua, Costa Rica, Panama, and Colombia (Cigliano et al. 2020).

The call consists of a series of 5–8 pulses (mean: 7; Fig. 43C, D) with a total call duration ranging from 105–156 ms and having a mean of ~125 ms (Table 1). The peak frequency of the entire call is ~14 kHz with a -20 dB frequency range spanning ~9–18 kHz, giving a bandwidth of ~9 kHz (Table 1). Pulse amplitudes either consistently increase or they increase and then decrease across the call (Fig. 43D).

Pulse durations, periods, and peak frequencies all increase across the call (Table 36). The low and high frequencies also increase across the call and the bandwidth of each pulse can vary from 5–9 kHz. Some calls have a conspicuous initial wing-opening sound with a duration of 11.6 ± 0.9 (n = 11 calls).

The calls of this species were previously described by Belwood and Morris (1987), Belwood (1988a), ter Hofstede et al. (2010), Jones et al. (2014), Falk et al. (2015), and Symes et al. (2016). In addition to acoustic signals, both males and females produce vibrational signals (described in Belwood 1988a).
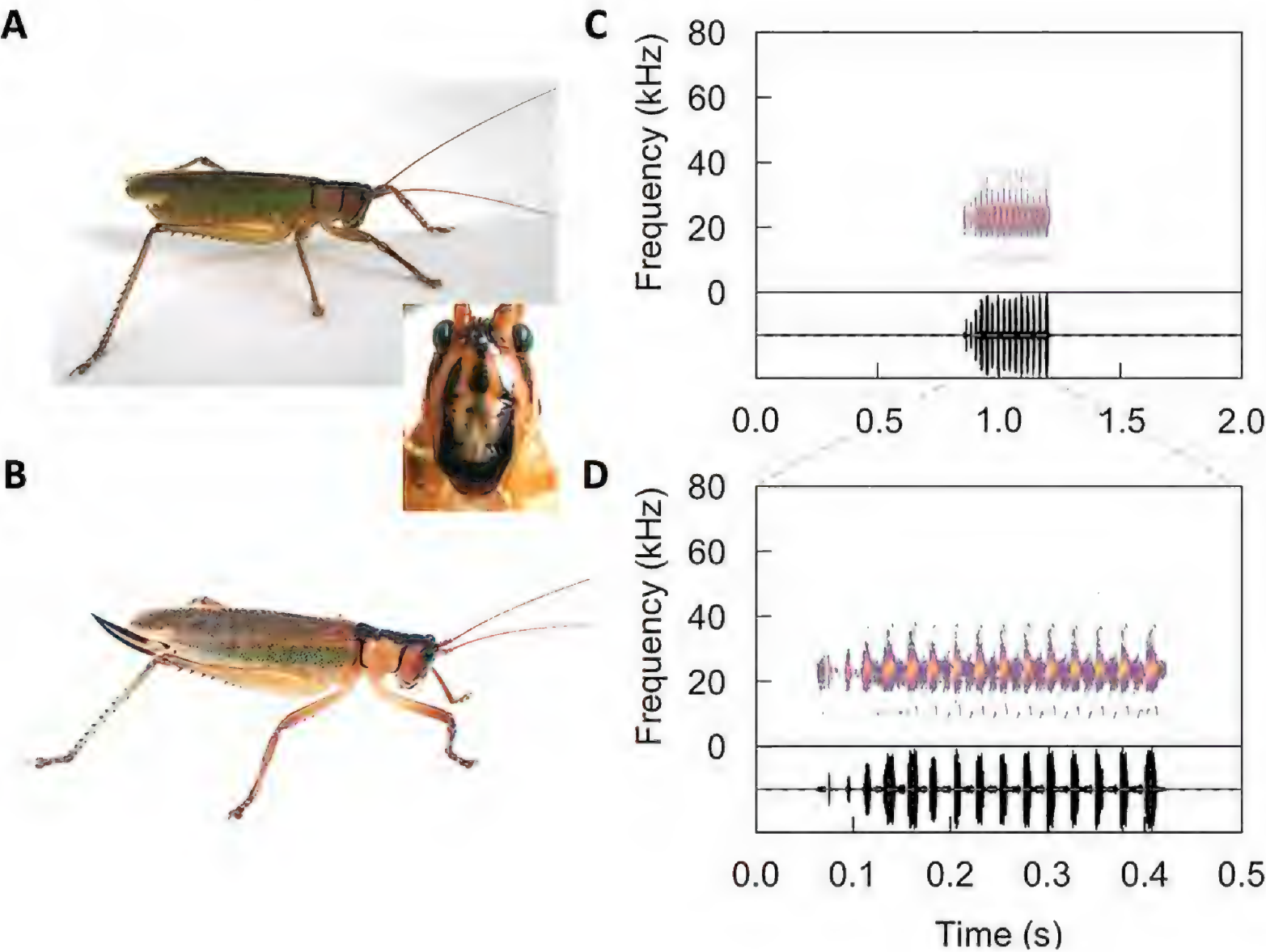

Fig. 43. Photographs and calling song spectrograms of *Balboana tibialis*. **A.** Male (photo credit: H. ter Hofstede); **B.** Female (photo credit: C. Kernan); **C.** and **D.** Spectrogram (top panel) and oscillogram (bottom panel) of one call at different time scales.

Table 36. Call pulse parameters of *Balboana tibialis* (4 individuals, 20 calls; mean ± SD); n = number of pulses measured.

Pulse Number (n)	Pulse Duration (ms)	Pulse Period (ms)	Peak Frequency (kHz)	Low Frequency (kHz)	High Frequency (kHz)	Bandwidth (kHz)
1 (20)	3.8 ± 0.8		12.4 ± 1.8	8.4 ± 1.0	16.8 ± 1.6	8.5 ± 2.2
2 (20)	6.1 ± 1.1	19.5 ± 2.3	13.0 ± 1.5	8.8 ± 0.5	16.2 ± 1.7	7.4 ± 2.1
3 (20)	7.6 ± 1.6	20.4 ± 1.6	13.2 ± 1.0	9.5 ± 1.2	16.7 ± 1.3	7.1 ± 2.3
4 (20)	8.6 ± 1.5	21.0 ± 2.0	14.1 ± 1.6	10.7 ± 1.8	16.1 ± 1.9	5.4 ± 3.3
5 (20)	10.2 ± 0.9	21.4 ± 2.2	14.1 ± 1.3	11.1 ± 1.5	16.2 ± 1.8	5.0 ± 3.0
6 (16)	9.8 ± 1.8	21.8 ± 1.6	14.4 ± 1.4	11.1 ± 2.1	17.1 ± 0.9	5.9 ± 2.8
7 (11)	9.2 ± 0.4	23.8 ± 1.0	14.9 ± 2.2	9.5 ± 1.9	17.5 ± 1.2	8.0 ± 2.3

Cocconotus wheeleri Hebard, 1927
Fig. 44 [MNHN-SO-2019-323, -324, -325, -326, -327, -328]

Cocconotus wheeleri is a large (1.32 ± 0.21 g, n = 18), cylindrical, tan katydid with green markings on the wings, significantly darker dorsal surface of pronotum (black to dark brown) compared to tan colored sides of pronotum, and five black vertical lines on the face (Fig. 44A, B). This species is only known from Panama (Cigliano et al. 2020).

The call consists of a series of 4–16 (mean: 11) pulses (Fig. 44C, D) with a total call duration ranging from ~79–355 ms and having a mean of ~250 ms (Table 1). The peak frequency of the entire call is ~25 kHz with a -20 dB frequency range spanning ~20–27 kHz, giving a bandwidth of ~7 kHz (Table 1). The first 2–3 pulses are much lower in amplitude than the rest of the pulses, which are usually quite constant in amplitude (Fig. 44C, D), although in some individuals the pulse amplitudes increase and then decrease over the call.

The first two pulses are shorter in duration than the rest of the pulses (Table 37). Excluding the first two pulses, both pulse duration and pulse period increase slightly across the call (Table 37). The pulses in the call are all similar in their spectral properties (Table 37).

The calls of this species were previously described by Belwood and Morris (1987), Belwood (1988a), and Symes et al. (2016). In addition to acoustic signals, both males and females produce vibrational signals (described in Belwood 1988a).

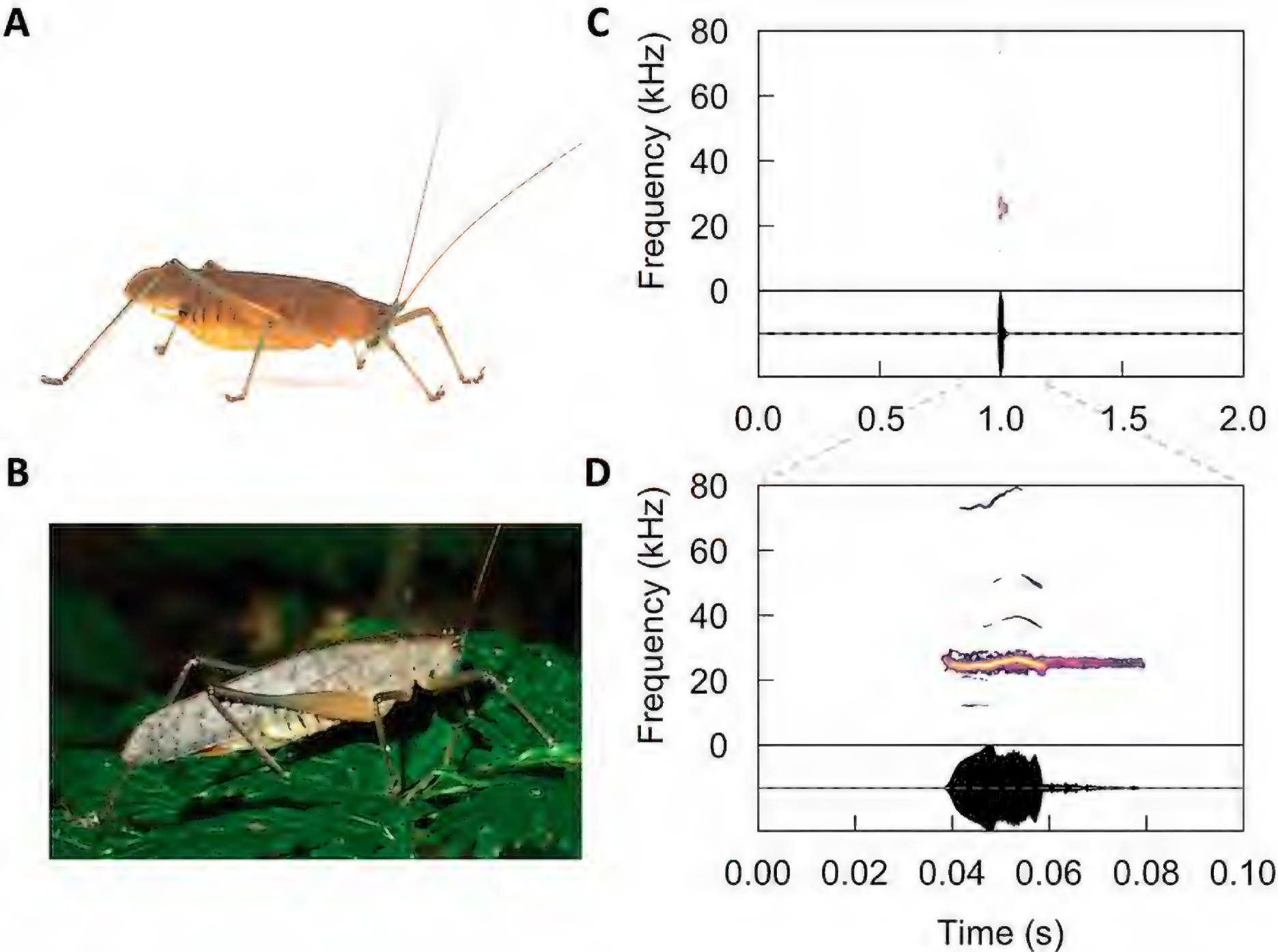**Fig. 44.** Photographs and calling song spectrograms of *Cocconotus wheeleri*. **A.** Male, inset showing striped face (one of the five black lines is obscured by white glare; photo credit: H. ter Hofstede); **B.** Female (photo credit: T. Robillard); **C.** and **D.** Spectrogram (top panel) and oscillogram (bottom panel) of one call at different time scales.

Table 37. Call pulse parameters of *Cocconotus wheeleri* (6 individuals, 60 calls; mean ± SD); n = number of pulses measured.

Pulse Number (n)	Pulse Duration (ms)	Pulse Period (ms)	Peak Frequency (kHz)	Low Frequency (kHz)	High Frequency (kHz)	Bandwidth (kHz)
1 (60)	5.4 ± 3.8		23.6 ± 1.7	20.2 ± 1.6	27.9 ± 1.3	7.7 ± 1.1
2 (60)	7.5 ± 2.9	17.1 ± 3.7	23.8 ± 1.3	20.7 ± 1.6	28.1 ± 1.2	7.5 ± 1.7
3 (60)	9.1 ± 2.7	20.8 ± 1.5	23.9 ± 1.4	21.0 ± 1.7	27.8 ± 1.0	6.9 ± 1.6
4 (60)	9.8 ± 2.1	21.8 ± 1.0	24.7 ± 0.9	21.2 ± 1.3	28.0 ± 1.3	6.9 ± 1.4
5 (60)	9.4 ± 1.8	23.8 ± 1.5	24.8 ± 0.8	21.4 ± 1.5	27.9 ± 1.2	6.5 ± 1.3
6 (58)	8.8 ± 2.2	23.4 ± 0.6	24.9 ± 0.8	21.4 ± 1.4	28.2 ± 1.5	6.8 ± 1.6
7 (55)	9.3 ± 1.7	23.2 ± 1.2	24.8 ± 0.7	21.3 ± 1.4	27.9 ± 0.9	6.7 ± 1.2
8 (47)	9.6 ± 0.9	22.8 ± 1.6	24.7 ± 1.0	21.4 ± 1.1	27.9 ± 1.0	6.5 ± 1.3
9 (42)	8.9 ± 2.1	22.9 ± 1.5	24.6 ± 0.8	20.9 ± 0.9	28.3 ± 1.2	7.3 ± 1.1
10 (37)	10.1 ± 1.8	23.0 ± 2.3	24.5 ± 0.7	20.9 ± 0.8	28.2 ± 1.5	7.2 ± 1.4
11 (36)	9.5 ± 1.7	24.7 ± 0.7	24.3 ± 0.6	21.0 ± 1.0	28.2 ± 1.5	7.2 ± 1.4
12 (31)	11.0 ± 2.6	23.7 ± 1.5	24.3 ± 0.8	21.0 ± 1.1	28.3 ± 1.7	7.2 ± 1.5
13 (27)	10.7 ± 1.7	24.5 ± 0.4	24.0 ± 0.7	20.9 ± 1.2	27.5 ± 0.7	6.5 ± 1.4
14 (16)	10.4 ± 2.2	25.3 ± 1.0	24.2 ± 0.8	20.7 ± 1.0	27.7 ± 0.9	6.9 ± 1.2
15 (9)	11.9 ± 2.5	25.8 ± 1.0	24.4 ± 0.8	20.8 ± 1.4	27.9 ± 0.9	7.1 ± 1.8

Docidocercus gigliotosi (Griffini, 1896)
Fig. 45 [MNHN-SO-2019-337, -338, -339, -340, -341, -342, -343]

Docidocercus gigliotosi is a medium-sized (1.26 ± 0.17 g, n = 22), cylindrical, tan katydid with dark and light brown banding on the dorsal surface of the abdomen and a light blue face (Fig. 45A, B). Some individuals have shiny, greenish-yellow coloration on the dorsal surface of the pronotum. This species is only known from Panama (Cigliano et al. 2020).

The call consists of 1–3 (mean: 1.6) identical pulses (Fig. 45C, D) with a total call duration ranging from ∼13 ms (single pulse) to 376 ms (3 pulses) and having a mean of ∼118 ms (Table 1). Each pulse has a sinusoidal shape (Fig. 45D) and a mean duration of ∼20 ms (Table 38). Of the 140 calls measured, 77 were a single pulse, 48 were two pulses, and 15 were three pulses. The peak frequency of each pulse (Table 38) and the entire call is ∼24 kHz with a -20 dB frequency range spanning ∼23.5–26 kHz, giving a narrow bandwidth of ∼2.5 kHz (Table 1). Pulse amplitudes are similar in calls with more than one pulse.

The calls of this species were previously described by Belwood and Morris (1987), Belwood (1988a), Morris et al. (1994), Römer et al. (2010), ter Hofstede et al. (2010), and Falk et al. (2015). In addition to acoustic signals, both males and females produce vibrational signals (described in Belwood 1988a, Römer et al. 2010).

Fig. 45. Photographs and calling song spectrograms of *Docidocercus gigliotosi*. **A.** Male (photo credit: C. Kernan); **B.** Female (photo credit: T. Robillard); **C.** and **D.** Spectrogram (top panel) and oscillogram (bottom panel) of one call at different time scales.

Table 38. Call pulse parameters of *Docidocercus gigliotosi* (7 individuals, 140 calls; mean ± SD); n = number of pulses measured.

Pulse Number (n)	Pulse Duration (ms)	Pulse Period (ms)	Peak Frequency (kHz)	Low Frequency (kHz)	High Frequency (kHz)	Bandwidth (kHz)
1 (140)	20.0 ± 1.4		24.2 ± 0.5	23.6 ± 0.5	25.5 ± 0.7	1.9 ± 0.5
2 (63)	19.2 ± 2.7	190.6 ± 34.1	24.0 ± 0.6	23.5 ± 0.7	25.9 ± 1.0	2.4 ± 1.3
3 (15)	19.5 ± 0.6	159.0 ± 11.7	24.1 ± 0.7	23.7 ± 0.7	25.5 ± 0.4	1.8 ± 0.4

Eubliastes pollonerae (Griffini, 1896)
Fig. 46 [MNHN-SO-2019-652, -653, -654, -655, -656]

Eubliastes pollonerae is a large (1.9 ± 0.37 g, n = 15), cylindrical, tan-colored katydid with dark anterior and posterior edges of the pronotum, a uniformly pinkish-beige face, and bright green eyes (Fig. 46A, B). This species is known from Costa Rica, Panama, and Colombia (Cigliano et al. 2020).

The call consists of two main pulses with what appear to be relatively high-amplitude wing-opening sounds before each pulse (Fig. 46C, D). The total call duration is ~37 ms not including the first wing-opening sound (Table 1) and ~55 ms with the wing-opening sound. The peak frequency of the entire call is ~24 kHz with a -20 dB range spanning ~21–25 kHz, giving a narrow bandwidth of 4 kHz (Table 1).

The two main pulses are very similar in duration and peak frequency (Table 39). The first wing-opening sound is longer, whereas the second wing-opening sound is shorter than the main pulses (Table 39). The peak frequency and low frequency of the wing-opening sounds are both lower than the main pulses, resulting in a greater bandwidth for the wing-opening sounds than the pulses (Table 39).

The calls of this species were previously described by Falk et al. (2015) and Symes et al. (2016).
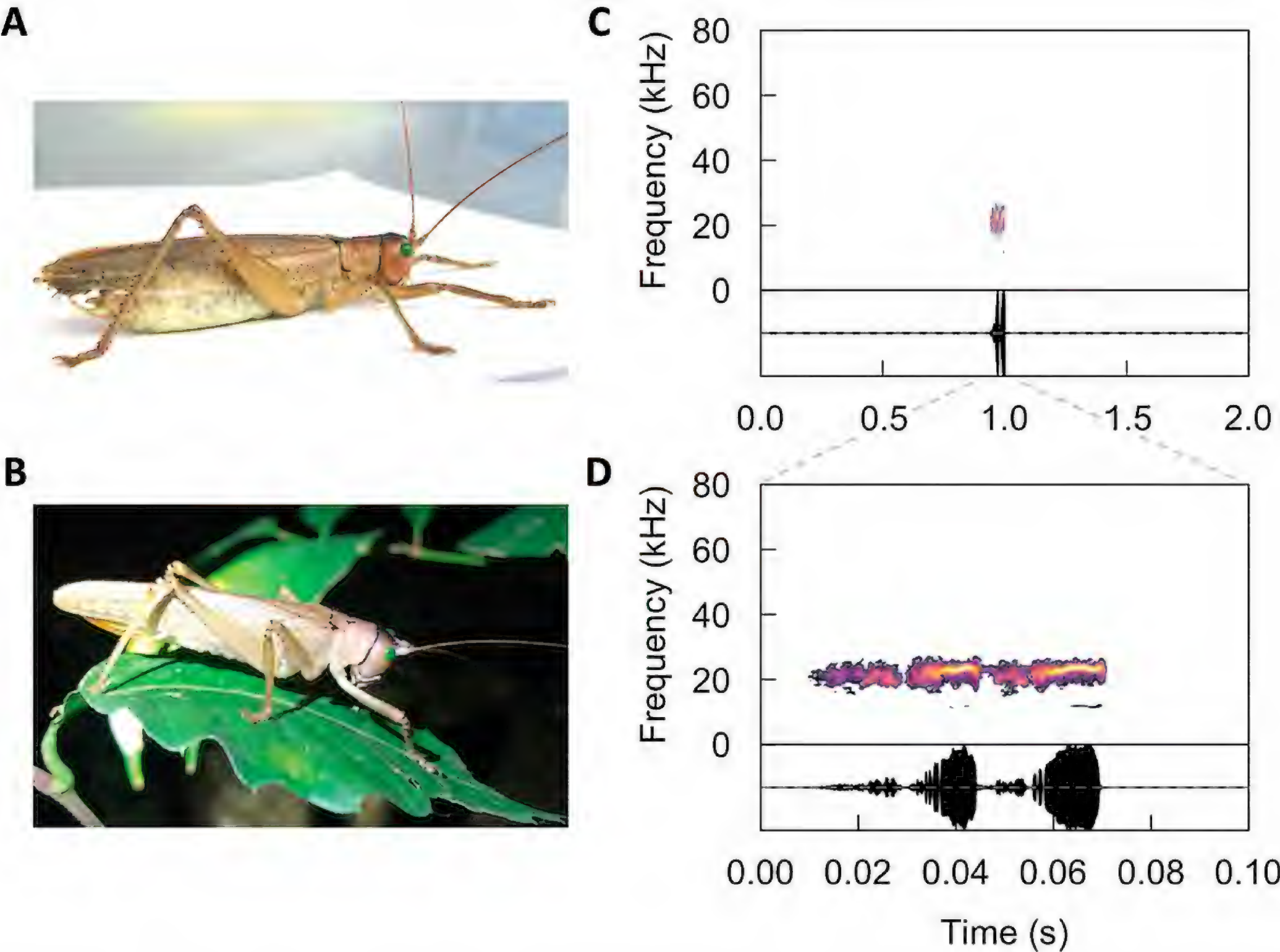
Fig. 46. Photographs and calling song spectrograms of *Eubliastes pollonerae*. **A.** Male (photo credit: H. ter Hofstede); **B.** Female (photo credit: C. Kernan); **C.** and **D.** Spectrogram (top panel) and oscillogram (bottom panel) of one call at different time scales.

Table 39. Call pulse parameters of *Eubliastes pollonerae* (5 individuals, 100 calls; mean ± SD); WO = wing-opening sound; n = number of pulses measured.

Pulse Number (n)	Pulse Duration (ms)	Pulse Period (ms)	Peak Frequency (kHz)	Low Frequency (kHz)	High Frequency (kHz)	Bandwidth (kHz)
WO1 (100)	17.8 ± 0.6		20.9 ± 1.2	17.2 ± 1.5	26.6 ± 1.9	9.4 ± 1.6
1 (100)	13.2 ± 1.7	20.1 ± 0.6	24.2 ± 1.5	21.9 ± 1.7	26.5 ± 1.6	4.6 ± 1.6
WO2 (100)	7.7 ± 1.2	16.8 ± 1.6	21.3 ± 1.1	17.8 ± 1.6	26.9 ± 1.9	9.1 ± 1.7
2 (100)	12.9 ± 1.8	9.8 ± 1.2	24.3 ± 1.3	22.4 ± 1.2	26.4 ± 1.8	4.1 ± 0.8

Idiarthron majus **Hebard, 1927**
Fig. 47 [MNHN-SO-2019-1096, -1097, -1098]

Idiarthron majus is a very large (2.38 ± 0.7 g, n = 3), robust and dark brown katydid (Fig. 47A, B). This species is only known from Panama (Cigliano et al. 2020).

The call consists of two pulses (pulse duration ~10–20 ms) with a pulse period of ~25 ms and a mean call duration of ~45 ms (Table 1). The peak frequency of the call is ~24 kHz, with a -20 dB range spanning ~20–30 kHz, giving a bandwidth of 10 kHz (Table 1). The first pulse is always shorter and much lower in amplitude than second pulse (Table 40). Both pulses are very similar in spectral properties to each other and the entire call (Table 40). Individual tooth strikes are visible on the spectrogram.

The calls of this species were previously described by Belwood and Morris (1987) and Belwood (1988a). In addition to acoustic signals, males produce vibrational signals (Belwood 1988a).
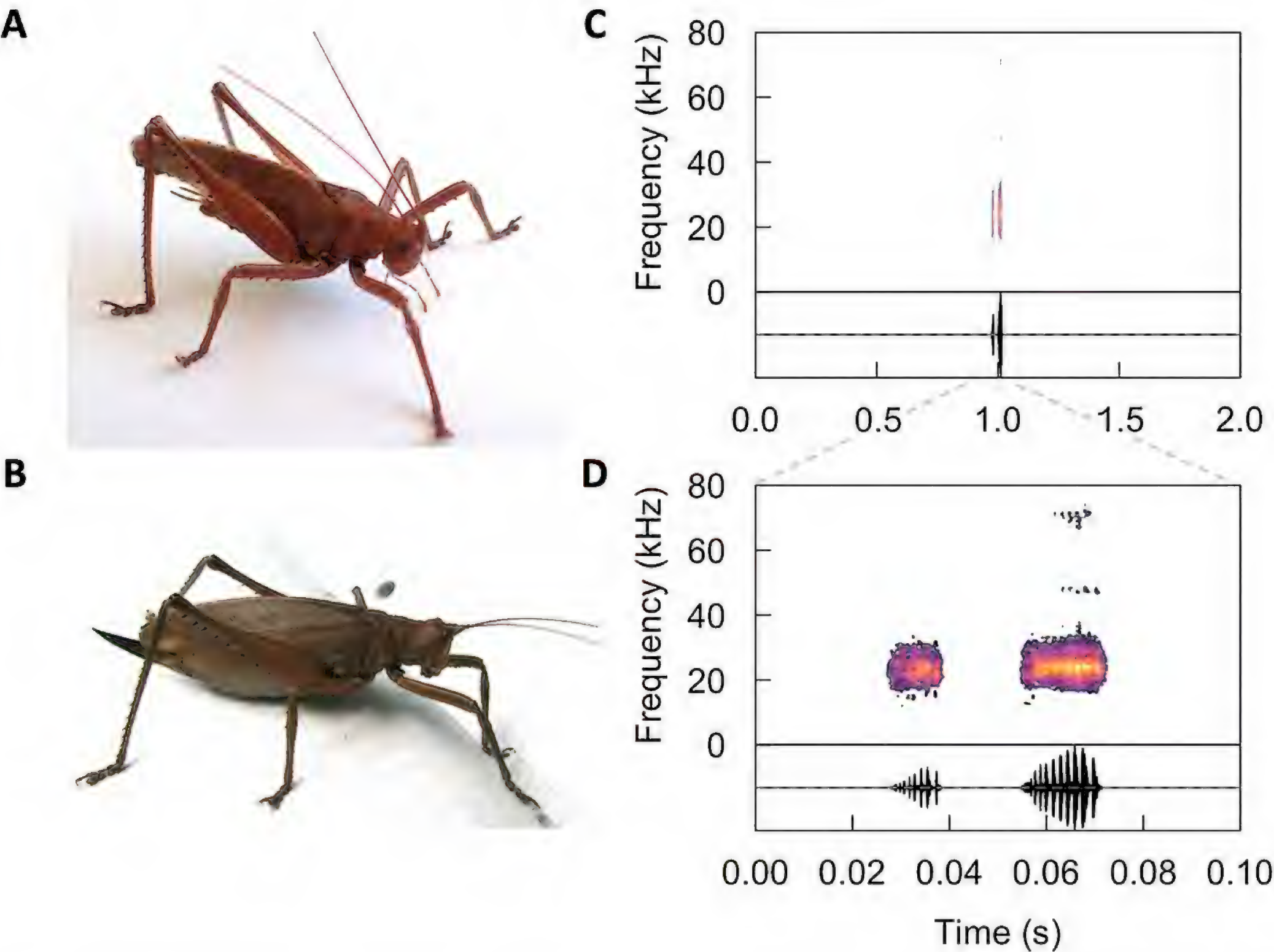
Fig. 47. Photographs and calling song spectrograms of *Idiarthron majus*. **A.** Male (photo credit: T. Robillard); **B.** Female (photo credit: H. ter Hofstede); **C.** and **D.** Spectrogram (top panel) and oscillogram (bottom panel) of one call at different time scales.

Table 40. Call pulse parameters of *Idiarthron majus* (3 individuals, 26 calls; mean ± SD); n = number of pulses measured.

Pulse Number (n)	Pulse Duration (ms)	Pulse Period (ms)	Peak Frequency (kHz)	Low Frequency (kHz)	High Frequency (kHz)	Bandwidth (kHz)
1 (26)	10.8 ± 1.3		23.4 ± 0.7	18.4 ± 0.4	31.4 ± 1.3	13.1 ± 0.9
2 (26)	18.6 ± 1.9	27.2 ± 0.5	24.4 ± 0.7	20.3 ± 1.1	29.2 ± 1.9	8.9 ± 1.4

Ischnomela gracilis Stål, 1873
Fig. 48 [MNHN-SO-2019-1099, -1100, -1101, -1102]

Ischnomela gracilis is a large (1.55 ± 0.17 g, n = 13) and very elongated tan-colored katydid with black knees, a yellow line along the anal margins of the tegmina, and conspicuous white ocelli on top of the head (Fig. 48A). This species is known from Costa Rica, Panama, Colombia, and Ecuador (Cigliano et al. 2020).

The call consists of a single pulse with a duration ranging from 8–14 ms and having a mean of ~11 ms (Table 1; Fig. 48B, C). The peak frequency of the call is ~74 kHz with a -20 dB range spanning 67–91 kHz, giving a broad bandwidth of ~24 kHz. The call also has significant energy at ~15 kHz, which is usually a lower amplitude than the peak frequency (Fig. 48C) but can also be equal in amplitude in some calls.

The calls of this species were previously described by ter Hofstede et al. (2010), Montealegre-Z (2012), and Jones et al. (2014).
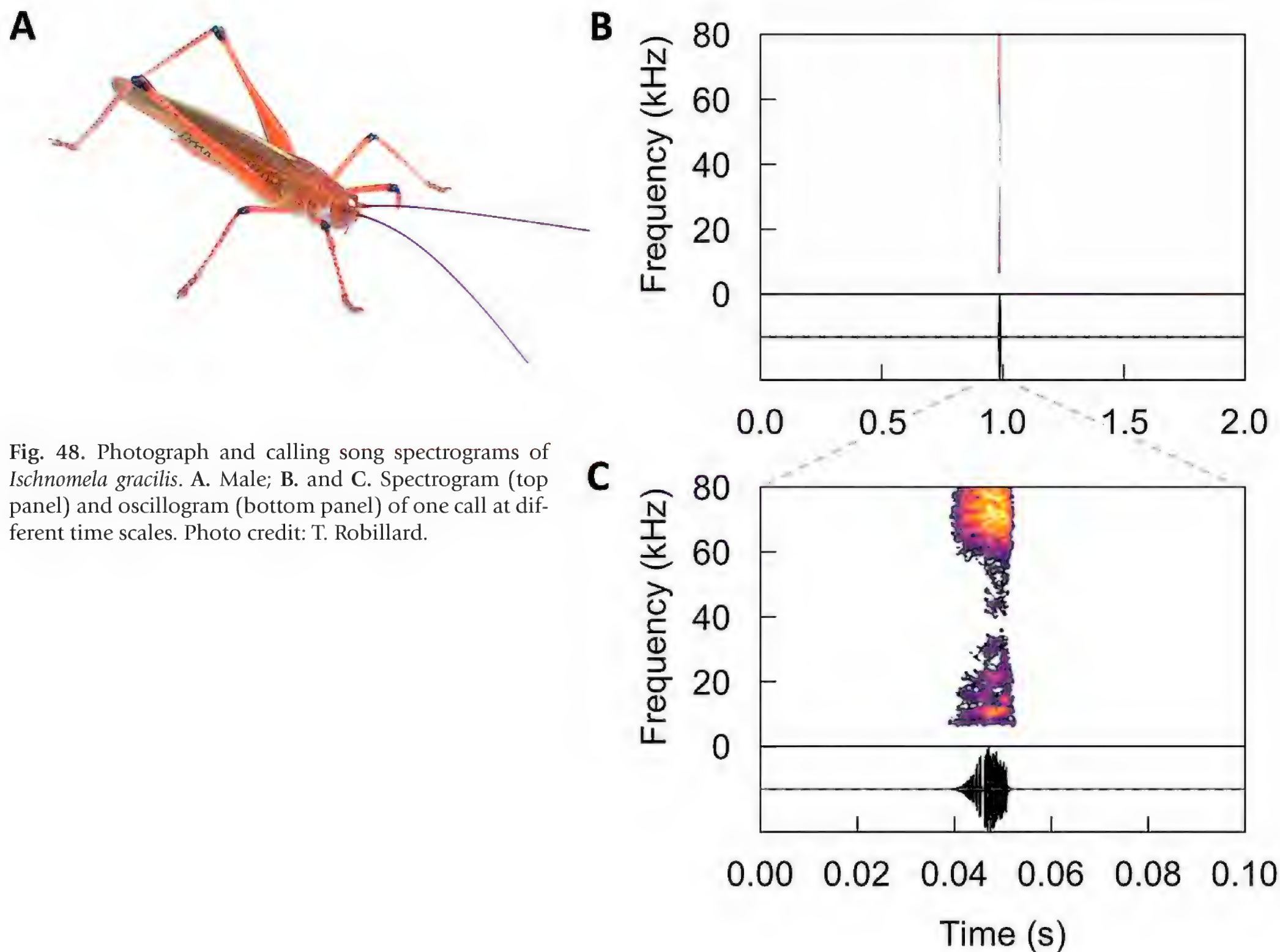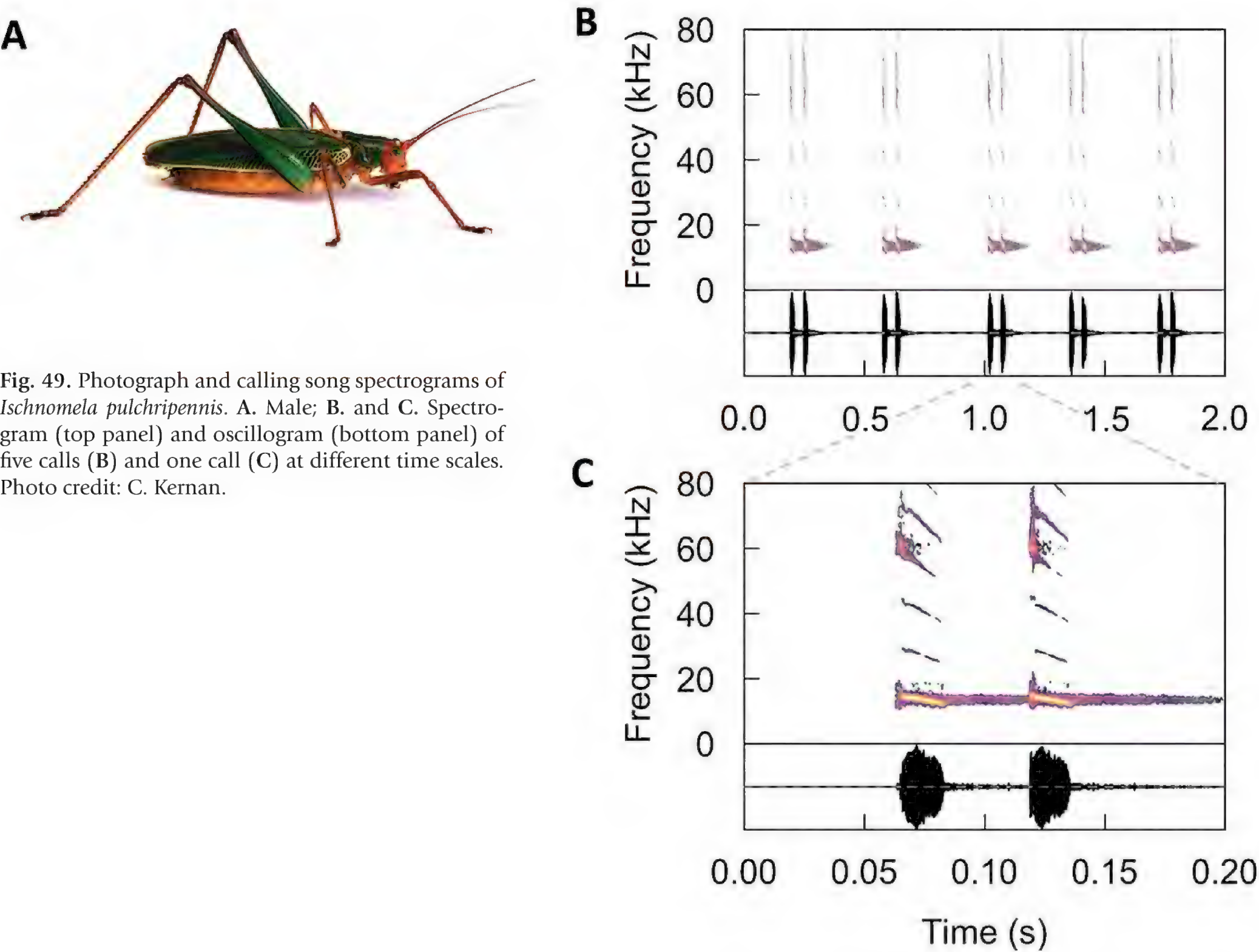

Fig. 48. Photograph and calling song spectrograms of *Ischnomela gracilis*. **A.** Male; **B.** and **C.** Spectrogram (top panel) and oscillogram (bottom panel) of one call at different time scales. Photo credit: T. Robillard.

Ischnomela pulchripennis **Rehn, 1906**
Fig. 49 [MNHN-SO-2019-1280, -1281, -1282]

Ischnomela pulchripennis is a very large (3.75 ± 0.14 g, n = 2) and cylindrical katydid with green wings, pronotum, and hind femurs and a tan body (Fig. 49A). This species is known from Panama (Nickle 1992) and Costa Rica (Cigliano et al. 2020).

The call consists of two pulses with a consistent call duration of 69 ms (Table 1; Fig. 49B, C). Calls can be produced individually, in small groups, or continuously with a period of ~200–250 ms for long periods of time. The peak frequency of the entire call is ~14 kHz with a -20 dB range spanning ~12–15 kHz, giving a bandwidth of ~3 kHz (Table 1). The call has a significant harmonic structure, with energy at multiples of the fundamental/peak frequency, especially at ~60 kHz (Fig. 49C). The pulses are the same in amplitude, duration, and spectral properties (Table 41). Each pulse decreases slightly in frequency, starting at ~15 kHz and ending at ~12.5 kHz.

The calls of this species were previously described by Belwood (1988a). In addition to acoustic signals, males produce vibrational signals (Belwood 1988a).

Fig. 49. Photograph and calling song spectrograms of *Ischnomela pulchripennis*. **A.** Male; **B.** and **C.** Spectrogram (top panel) and oscillogram (bottom panel) of five calls (**B**) and one call (**C**) at different time scales. Photo credit: C. Kernan.

Table 41. Call pulse parameters of *Ischnomela pulchripennis* (3 individuals, 15 calls; mean ± SD); n = number of pulses measured.

Pulse Number (n)	Pulse Duration (ms)	Pulse Period (ms)	Peak Frequency (kHz)	Low Frequency (kHz)	High Frequency (kHz)	Bandwidth (kHz)
1 (15)	17.1 ± 0.9		13.7 ± 0.3	12.2 ± 0.3	15.3 ± 0.1	3.1 ± 0.2
2 (15)	16.5 ± 0.8	52.5 ± 1.4	13.5 ± 0.3	12.3 ± 0.2	15.3 ± 0.3	3.0 ± 0.2

Pristonotus tuberosus (Stål, 1875)
Fig. 50 [MNHN-SO-2019-1794, -1795, -1796]

Pristonotus tuberosus is a very large (5.24 ± 0.48 g, n = 5), brown katydid with two cream-colored stripes on the face and green mottling on the wings (Fig. 50A). It is very well-camouflaged when resting on lichen-covered bark (Fig. 50B). This species is known from Panama and Colombia (Cigliano et al. 2020).

The call consists of a single pulse with a duration ranging from 14–20 ms and having a mean of ~17.5 ms (Table 1; Fig. 50C, D). The peak frequency of the call is ~11 kHz with a -20 dB range spanning 8–17 kHz, giving a bandwidth of ~9 kHz. Individual tooth strikes are visible on the oscillogram (Fig. 50D).

The calls of this species were previously described by Belwood and Morris (1987) and Belwood (1988a). Females have been observed to produce vibrational signals (Belwood 1988a).
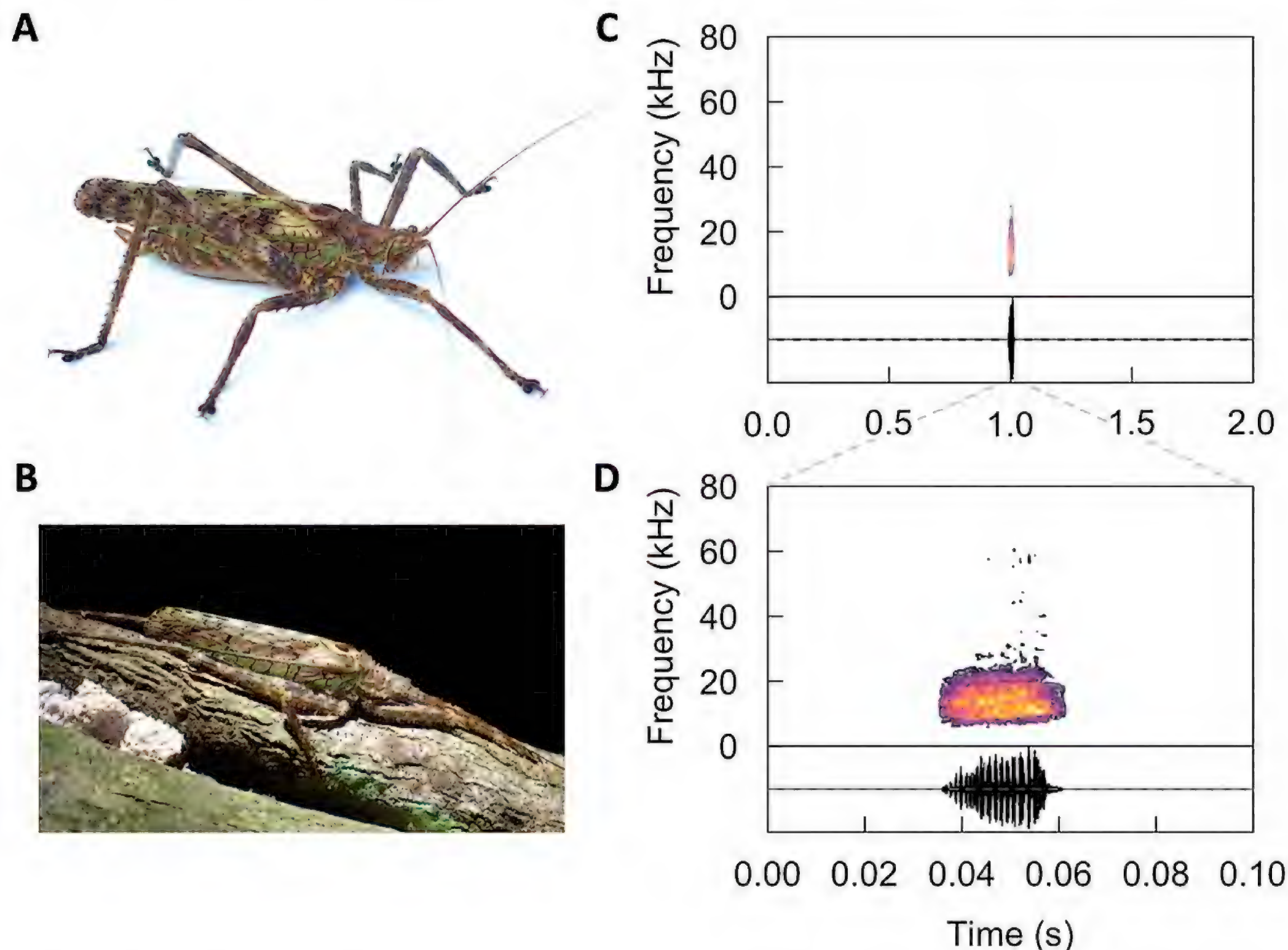
Fig. 50. Photographs and calling song spectrograms of *Pristonotus tuberosus*. **A.** Male; **B.** Male resting on branch; **C.** and **D.** Spectrogram (top panel) and oscillogram (bottom panel) of one call at different time scales. Photo credit: T. Robillard.

Scopiorinus fragilis (Hebard, 1927)
Fig. 51 [MNHN-SO-2019-1800, -1801, -1802]

Scopiorinus fragilis is a mid-sized (0.54 ± 0.08 g, n = 7), slender, and cylindrical green katydid (Fig. 51A, B). This species is only known from Panama (Cigliano et al. 2020).

The call consists of a "chirp" (groups of pulses; Fig. 51C, D) that is produced singly, in small groups, or every 0.5–2 s for long periods of time. Chirp durations range from 53–70 ms with a mean duration of ~60 ms (Table 1). The peak frequency of the call is ~26 kHz with a -20 dB range spanning ~22–32 kHz, giving a bandwidth of ~10 kHz.

The chirp consists of 6 pulses with the first two pulses being short (5–10 ms) and very low amplitude, and pulses 3–6 being longer and higher amplitude (8–20 ms; Fig. 51D). It looks like sound is produced both during the wing opening and wing closing movements resulting in pulses that vary in amplitude but have almost no silence between them (Fig. 51D). High-speed video of males singing would be helpful in confirming that this is the mechanism responsible for these chirps with very short silent periods between pulses.

The calls of this species were previously described by Belwood (1988a). In addition to acoustic signals, males produce vibrational signals (Belwood 1988a).
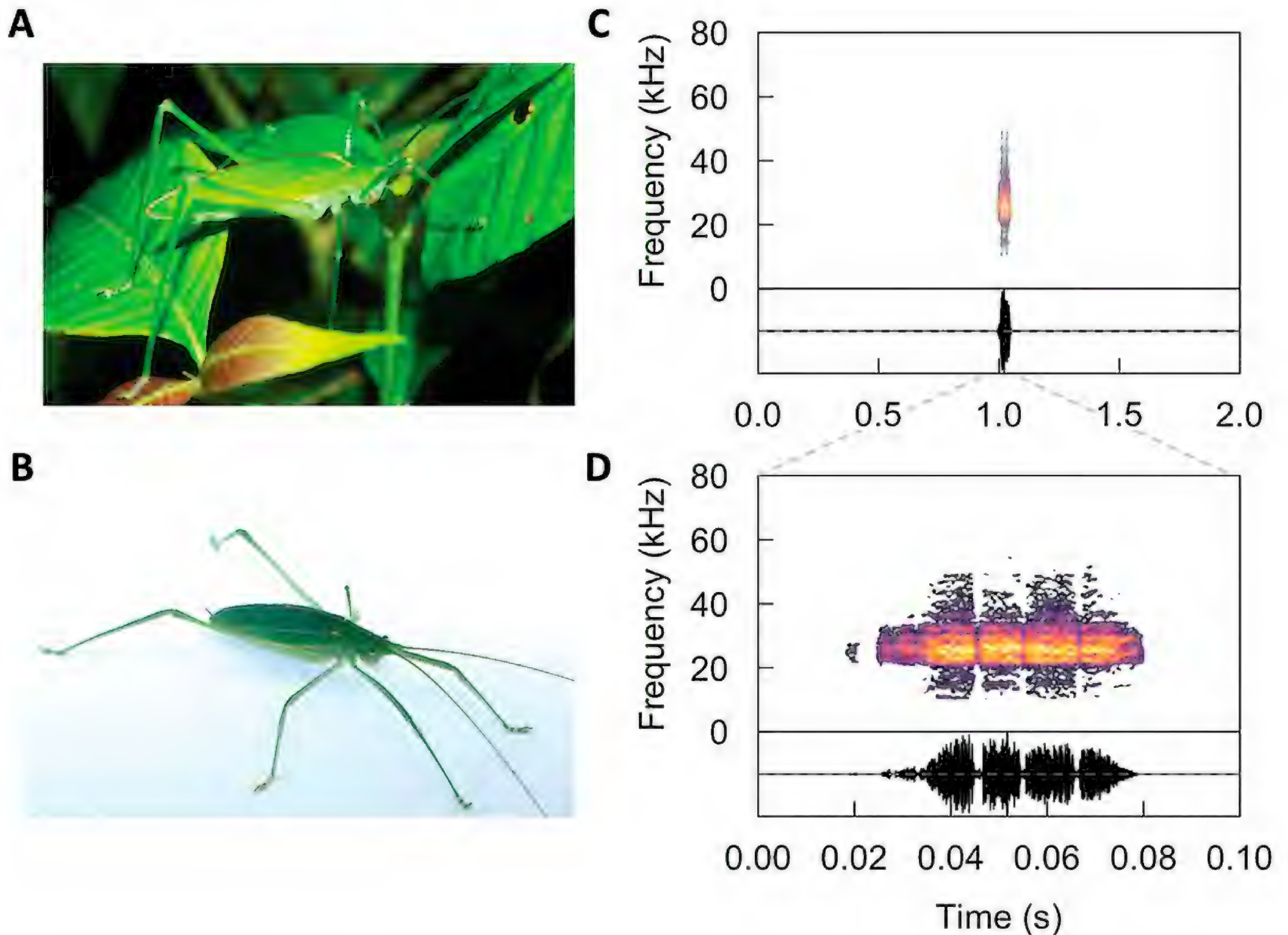
Fig. 51. Photographs and calling song spectrograms of *Scopiorinus fragilis*. **A.** Male (photo credit: C. Kernan); **B.** Female (photo credit: T. Robillard); **C.** and **D.** Spectrogram (top panel) and oscillogram (bottom panel) of one call at different time scales.

Thamnobates subfalcata **Saussure & Pictet, 1898**
Fig. 52 [MNHN-SO-2019-1817, -1818, -1819]

Thamnobates subfalcata is a mid-size (0.63 ± 0.19 g, n = 24), brown, cylindrical katydid with a darkened stridulatory area in males (Fig. 52A, B). This species is only known from Panama (Cigliano et al. 2020).

The call consists of 2 pulses (Fig. 52C, D) with a total call duration ranging from 21–33 ms and having a mean of 31 ms

(Table 1). The peak frequency of the entire call is ~19 kHz with a -20 dB frequency range spanning ~17.5–21 kHz, giving a bandwidth of ~3.5 kHz (Table 1). The two pulses are usually equal in amplitude (Fig. 52D). Wing-opening sounds are usually seen before the first pulse.

The first pulse is shorter in duration than the second pulse and the two pulses are similar in their spectral properties (Table 42).

An oscillogram of the call of this species is given in Lang et al. (2005).
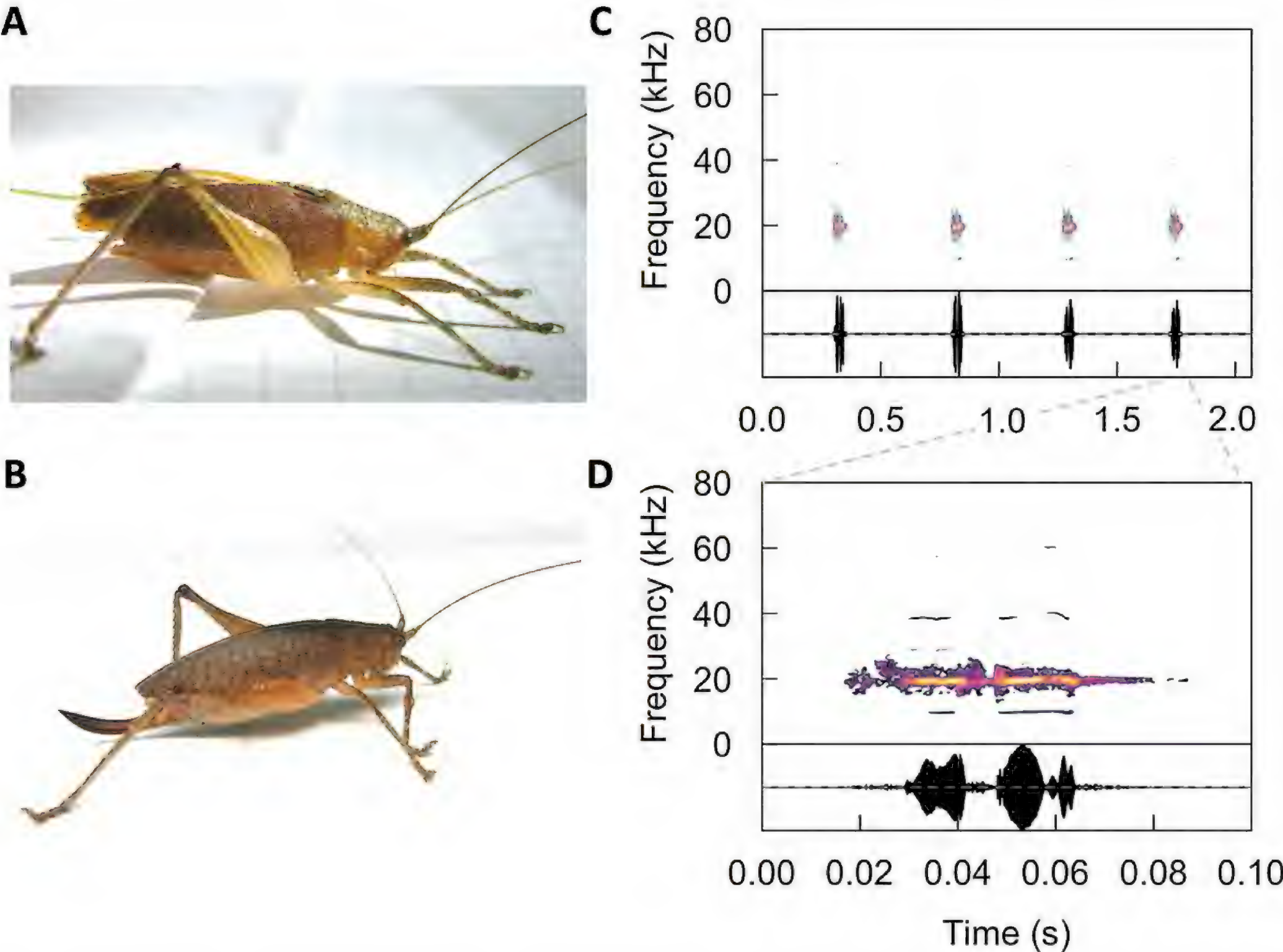
Fig. 52. Photographs and calling song spectrograms of *Thamnobates subfalcata*. **A.** Male; **B.** Female; **C.** and **D.** Spectrogram (top panel) and oscillogram (bottom panel) of four calls (**C**) and one call (**D**) at different time scales. Photo credit: H. ter Hofstede.

Table 42. Call pulse parameters of *Thamnobates subfalcata* (3 individuals, 15 calls; mean ± SD); n = number of pulses measured.

Pulse Number (n)	Pulse Duration (ms)	Pulse Period (ms)	Peak Frequency (kHz)	Low Frequency (kHz)	High Frequency (kHz)	Bandwidth (kHz)
1 (15)	11.1 ± 0.3		18.7 ± 0.3	17.9 ± 0.5	20.7 ± 0.6	2.8 ± 0.4
2 (15)	14.1 ± 3.0	16.5 ± 0.4	19.0 ± 0.2	18.1 ± 0.4	20.9 ± 1.0	2.8 ± 0.6

Discussion

The data presented in this study demonstrate the incredible diversity of the acoustic signals of Neotropical katydids. In this discussion, we comment on overall patterns seen in these data and suggest topics for future studies, but we refrain from detailed statistical analyses until a suitable phylogenetic framework is available for these species. In general, calls varied enormously in duration, temporal patterning, peak frequency, and bandwidth both across and within subfamilies.

For the species studied here, call duration ranged from a single 1.7 ms pulse by *Anaulacomera* "goat" to the continuous calls of some of the conocephaline katydids, such as *Eppia truncatipennis*, which calls repeatedly for 20 seconds at a time. Species in the Conocephalinae tend to produce longer calls than those in the Phaneropterinae and Pseudophyllinae, mostly due to repetition of the base call or pulse many times over a long period of time. However, several conocephaline species produce very short calls at long intervals (*Copiphora brevirostris*, *Subria sylvestris*, and *Vestria punctata*). The Pseudophyllinae that we recorded all produce short calls, ranging from a single pulse of 10 ms (*Ischnomela gracilis*) to a call of 11 pulses over 250 ms (*Cocconotus wheeleri*), consistent with previous reports of short and sporadic calling in this subfamily in the Neotropics (Rentz 1975, Belwood and Morris 1987, Belwood 1988a, Morris et al. 1994). However, some Neotropical pseudophyllines are known to produce longer calls (e.g., *Mimetica mortuifolia* from Panama, 1.2–2.1 s: Belwood 1988a; *Ottotettix smaragdopoda* from Ecuador, 600 ms: Braun 2011b). Within the Phaneropterinae, call durations varied from a single pulse of 1.7 ms (*Anaulacomera* "goat") to a call of 8 pulses over 6 seconds (*Microcentrum* "polka"), but many combinations of pulse numbers and call durations are found across the species in this subfamily (Table 1). Heller et al. (2015) reviewed the acoustic characteristics of 330 phaneropterine katydid species and reported a median call duration of 1 second, whereas the median call duration in our sample of 31 species was only 70 ms. In addition, although *Microcentrum* "polka" produces a long duration call (~6 s), it consists of very short pulses (2 ms) produced at long intervals (~1 s), making the duty cycle of the call (the proportion of time occupied by sound) very low. Our data suggest that, similar to Neotropical forest pseudophyllines, Neotropical phaneropterines have short calls compared to phaneropterine species from other parts of the world.

In the Neotropics, continuously calling katydid species are generally found in dense secondary growth in clearings or fields, whereas species with short and sporadic calls are more commonly found in forest habitats (Belwood and Morris 1987, Greenfield 1990), although there are some nocturnal Neotropical forest species that also call frequently (e.g., *Ischnomela pulchripennis* from Panama, Belwood and Morris 1987; *Typophyllum erosifolium* from Ecuador, Braun 2015b). There are several factors that might contribute to this general pattern: predation, habitat structure, and reproductive strategy. One family of bats that is endemic to the Neotropics (the Phyllostomidae) has diversified to include species with a wide range of foraging strategies, including species that specialize on locating prey by eavesdropping on their acoustic signals (Belwood 1988b, Kalko et al. 1996, Falk et al. 2015, Denzinger et al. 2018). Katydids comprise a large proportion of the diet of these bat species (Belwood 1988a, Römer et al. 2010, ter Hofstede et al. 2017). Katydids that call sporadically are more difficult for eavesdropping bats to locate than those that call frequently (Belwood and Morris 1987, ter Hofstede et al. 2008). Bat species that use this eavesdropping foraging strategy are captured in mistnets in forest habitats but not in fields or clearings (Belwood 1988a). These patterns of bat and katydid activity led to the hypothesis that eavesdropping by phyllostomid bats in the Neotropics selected for reduced acoustic signaling in forest-dwelling Neotropical katydid species (Rentz 1975, Belwood and Morris 1987, Belwood 1988a, Morris et al. 1994) compared to tropical forests in other parts of the world, where bats with this foraging strategy are either absent or rare (Heller 1995).

The structure of a habitat can influence the transmission of acoustic signals (Römer and Lewald 1992, Römer 1998) and might also contribute to differences in katydid calls between habitats. Highly repetitive signals appear adapted to allow receivers to locate the source of the sound in densely structured habitats, such as tall grasses in fields, where signal can be lost and gained as the receiver moves through the vegetation (Römer and Lewald 1992, Römer 1998, Kostarakos and Römer 2010), whereas mature forests with open spaces might facilitate communication with short and infrequent acoustic signals.

Both reproductive strategies and habitat use differ between the subfamilies of katydids (Gwynne 2001). Male katydids produce a spermatophore that is transferred to the female during mating (Gwynne 1990). Female katydids can gain nutritional benefits by eating the gelatinous, non-sperm-containing component of the spermatophore after mating (Gwynne 1988, Simmons 1994). The size of the spermatophore varies enormously between katydid species and is typically very small in conocephalines compared to phaneropterines and pseudophyllines (Gwynne 1977, Gwynne 1990, Vahed and Gilbert 1996). A large spermatophore can benefit males by acting as parental investment in offspring and protecting the sperm from female consumption (Gwynne 1990, Vahed and Gilbert 1996, McCartney et al. 2008). In some katydid species, the spermatophore is so large that it can even lead to sex role reversal due to the large male investment in reproduction, with males becoming choosy about mates and females competing for matings (Gwynne 1981, Simmons 1992, Ritchie et al. 1998). Since conocephalines are usually found in secondary growth and fields and phaneropterines and pseudophyllines are usually found in forests, some of the difference in acoustic signaling investment might be due to trade-offs in male reproductive investment (calling activity vs. spermatophore size) and sexual selection (male choosiness related to spermatophore size) (Gwynne 2001, del Castillo and Gwynne 2007 and corrigendum). However, exceptions to these taxonomic habitat associations support the additional role of predation and acoustic transmission in shaping Neotropical katydid calls. For example, the forest-dwelling conocephaline *Copiphora brevirostris* has a short call, sporadic sound production, and a large spermatophore (Belwood and Morris 1987, Belwood 1988a). Likewise, the forest-dwelling pseudophylline *Ischnomela pulchripennis* calls frequently, but does so from the protection of a spiny bromeliad in the forest (Belwood and Morris 1987).

Peak frequencies of the calls recorded in this study ranged from 10 kHz (many species) to 74 kHz (*Ischnomela gracilis*) (Table 1, Fig. 2), although most katydid species (86%) had peak frequencies between 10 and 30 kHz. We did not record any species with unusually low frequency calls, as have been documented for tropical forests in Southeast Asia (Malaysia: *Tympanophyllum arcufolium*, 0.6 kHz; Heller 1995), India (*Onomarchus uninotatus*, 3 kHz: Diwakar and Balakrishnan 2007a; Rajaraman et al. 2013), Africa (Tanzania: *Aerotegmina megaloptera* and *A. vociferator*, 2 kHz: Heller and Hemp 2019), the Caribbean (Guadeloupe: *Xerophyllopteryx fumosa*, 3 kHz: Stumpner et al. 2013), and South America (Brazil: *Paracycloptera grandifolia*, 3 kHz: Dias et al. 2017). It is possible that we are missing data on katydid species with low frequency calls in

Fig. 53. Relationships between call peak frequency (kHz) and mean mass (mg) for 49 katydid species from Panama. **A**. All data for each subfamily. Points surrounded by grey dashed circles appear to be outliers for each subfamily (green circle at 74 kHz = *Ischnomela gracilis;* red triangle at 3.4 g = *Philophyllia ingens;* red triangle at 4.2 g = *Steirodon stalii*); **B**. Data for families Phaneropterinae (red triangles) and Pseudophyllinae (green circles) with outliers removed. Lines are linear regression lines.
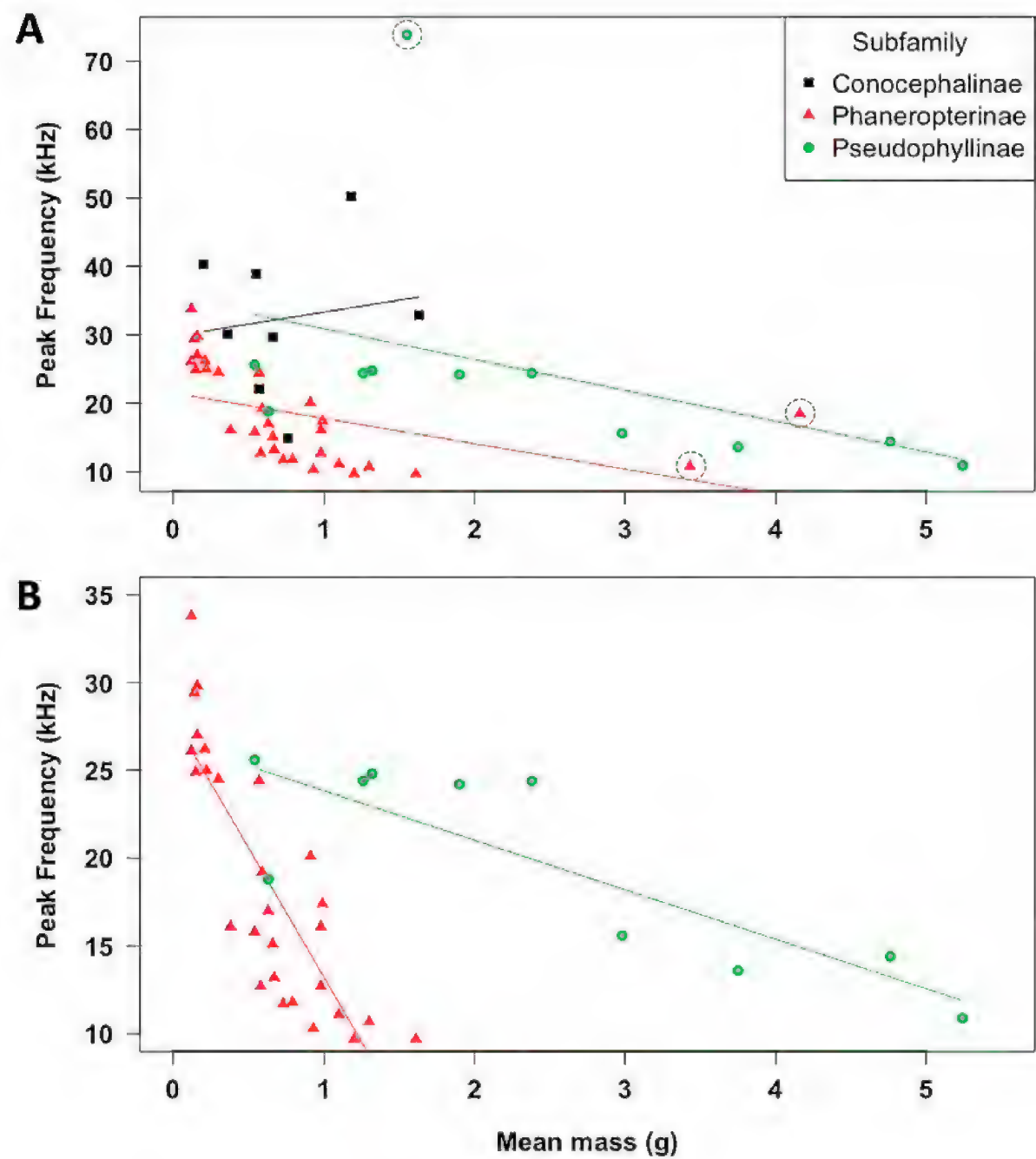
Central America, but it is interesting to speculate if the absence of low frequency calling species could be related to predation pressure as well. Morris et al. (1994) suggested that very high frequency calls in Neotropical katydids could be a defense against eavesdropping bats since high frequency sounds do not travel as far as low frequency sounds due to higher attenuation. Perhaps there is also selection against low-frequency calls in Neotropical regions where eavesdropping bat species specialize on low-frequency calling prey. Although most bats have very poor hearing in the range of 2-6 kHz (Neuweiler 1984), eavesdropping gleaning bat species for which data are available appear to be more sensitive to lower frequencies than other bat species (Neuweiler 1990). In particular, the Neotropical bat species *Trachops cirrhosus* is especially sensitive to frequencies between 0.5–3 kHz, corresponding with the frequencies of sympatric frog calls, one of their favorite prey (Ryan et al. 1983). Interestingly, two pseudophylline species with low frequency calls were documented for the Caribbean island of Guadeloupe (Stumpner et al. 2013), which has frugivorous phyllostomid bat species but no eavesdropping gleaning bat species (Baker et al. 1978).

Previous studies have documented a negative relationship between call frequency and measures of body size, i.e., smaller katydids produce higher frequency calls than larger katydids (Heller et al. 2006, Montealegre-Z 2009, Montealegre-Z et al. 2017). Montealegre-Z et al. (2017) found strong relationships between call frequency and both body size metrics (pronotum and mid-femur length) and specific sound generating structures on the wings (file and mirrors) for 94 katydid species with phylogenetic controls. Measures of sound generating structures were better at predicting call frequency than body size measures in general (Montealegre-Z et al. 2017). For the species in our study, there was no significant re-

lationship between mean call peak frequency and mass when testing all species together (Fig. 53; Supplemental material). However, there was a significant relationship between these two variables for species in the family Phaneropterinae (R^2 = 0.22, $F_{1,28}$ = 8.0, P = 0.008). Two phaneropterine species (*Philophyllia ingens* and *Steirodon stalii*) were more than twice the mass of the next heaviest phaneropterine species and appear to be outliers (Fig. 53A). When these two species were excluded from analysis, the variance in call frequency explained by mass increased (R^2 = 0.70, $F_{1,26}$ = 61.8, P < 0.001; Fig. 53B). Call frequency was not significantly related to mass in the Pseudophyllinae, but one species (*Ischnomela gracilis*) produces calls that are three times higher in frequency than the next highest pseudophylline species and appears to be an outlier (Fig. 53A). When this species was excluded from analysis, there was a significant relationship between call frequency and mass for the Pseudophyllinae as well (R^2 = 0.70, $F_{1,8}$ = 18.5, P = 0.003; Fig. 53B). Our results support previous studies showing a relationship between size and call frequency, but the nature of this relationship, i.e., the slope, might be different between subfamilies.

Both temporal and spectral properties of calls are important for identifying a potential mate of the same species in katydids (Bailey and Robinson 1971, Tauber and Pener 2000, Guerra and Morris 2002, Deily and Schul 2004, 2006, Bush and Schul 2006, Bush et al. 2009, Triblehorn and Schul 2009, Cole 2010, Hartbauer and Römer 2014). Most of the species we recorded produce broadband calls (-20 dB bandwidth of ~10 kHz or greater), but several species in the Phaneropterinae and Pseudophyllinae produce a tonal call, meaning it is a very narrowband signal (e.g., species with -20 bandwidths <4.4 kHz; Phaneropterinae: *Hyperphrona irregularis* = 3.9 kHz, *Philophyllia ingens* = 3.7 kHz, *Viadana*

brunneri = 4.2 kHz; Pseudophyllinae: *Docidocercus gigliotosi* = 2.6 kHz, *Eubliastes pollonerae* = 4.3 kHz, *Ischnomela pulchripennis* = 3.2 kHz, *Thamnobates subfalcata* = 3.4 kHz; Table 1). Chivers et al. (2017) found that a shorter stridulatory file and higher tooth density in the file corresponds with more tonal calls in katydids, providing predictions for the morphology of the sound generating structures in the species recorded here. Interestingly, the species that we recorded with narrowband calls are also species that produce very short calls of only one or two pulses. Two other species produce calls of only a single pulse but have greater bandwidth calls (Phaneropterinae: *Anaulacomera* "goat" = 9.9 kHz; Pseudophyllinae: *Ischnomela gracilis* = 24.1 kHz; Table 1). How these insects detect and recognize this short signal lacking a strong temporal pattern within the noise of a tropical forest is a fascinating question for future investigation (Lang et al. 2005). That these short and indistinct calls are usually narrowband might be adaptive. Within the auditory system of crickets and katydids, interneurons tuned to specific frequencies of biological importance can be found (Kostarakos et al. 2008, Stumpner and Nowotny 2014). These neurons are more narrowly tuned when species live in habitats with higher levels of background noise in the frequency range of the signal (Schmidt et al. 2011). We might predict that the katydid species with short and narrowband calls have an auditory interneuron that is narrowly tuned to the call of the male and acts as a matched filter to allow these species to detect the call in background noise (Schmidt and Balakrishnan 2015, Römer 2016). *Ischnomela gracilis*, on the other hand, has a short and broadband signal, but calls at an extremely high frequency (74 kHz) that is otherwise only produced by bats for echolocation in this community. It is also possible that these species compensate for their short signals by simultaneously signaling in other modalities. For example, males of many Neotropical pseudophylline species, including *Docidocercus gigliotosi* and *Ischnomela pulchripennis*, are known to alternate between acoustic and vibrational signaling (Belwood 1988a, Römer et al. 2010). Future studies could also investigate whether a combination of temporal, spatial, and frequency partitioning of acoustic space occurs in this community, as has been found in other insect communities (Sueur 2002, Diwakar and Balakrishnan 2007a,b, Schmidt et al. 2012, Montealegre-Z et al. 2014)

The majority of calls described here consist of a sequence of broadband pulses with stereotypical pulse durations and periods that do not overlap with other recorded species. These temporal differences provide a mechanism by which individuals can identify a potential mate. The most subtle difference in call structure between two species is that of the congeneric species *Euceraia atryx* and *E. insignis*. Males of these species both produce calls with overlapping ranges of the number of pulses, pulse durations, and spectral properties (Table 1), but pulse periods range from 80–90 ms in *E. atryx* (Table 21) compared to 100–110 ms in *E. insignis* (Table 22), providing a temporal mechanism for discrimination. Interestingly, these *Euceraia* species are also among the most diversely colorful katydid species on Barro Colorado Island, Panama (Figs 24A, B, 25A, B). The role of visual cues or chemical cues in mating is unknown for the species described here and is understudied in katydids in general. Chemical cues appear to play a role in mate recognition in the *Mecopoda elongata* species complex in India (Dutta et al. 2018), suggesting that they might also play a role in mate recognition in Neotropical species with similar acoustic or visual cues. Studies on katydid acoustic signals have revealed the presence of cryptic species that are morphologically very similar but can be distinguished by acoustic signals (Walker 1964, Walker et al. 2003, Montealegre-Z et al. 2011, Heller et al. 2017) and also cases of morphologically distinct species that have extremely similar acoustic signals (Çiplak et al. 2009, Şirin et al. 2014, Grzywacz et al. 2017), emphasizing the importance of documenting acoustic signals for taxonomic and phylogenetic studies.

Bioacoustic monitoring is becoming an important tool for tracking and assessing habitats (Klingbeil and Willig 2015, Gibb et al. 2019, Hill et al. 2019), and a detailed knowledge of the acoustic signals of the species in a community is essential for this. Monitoring acoustic insects provides valuable and rapidly accessible information because these insects have specific habitat associations, rapid population changes, and are centrally located in food webs. In addition, the relatively low intraspecific variation in insect calls makes them tractable for machine learning approaches to sound detection and classification. However, the ability to employ machine learning is constrained by the availability of high quality, well-curated training data. Currently, when insects are represented in acoustic monitoring, they are often represented as a composite 'insects' class or as unique but unidentified sonospecies (Aide et al. 2013, Campos-Cerqueira et al. 2019). The lack of connection between the recorded sounds and the species of insect makes it difficult to connect the dynamics of individual insect species with the rich natural history of these species. Careful taxonomic work and call descriptions are essential to developing acoustic monitoring capabilities.

Conclusions

Our goals in publishing these data are to provide detailed descriptions and recordings of the acoustic signals of many Neotropical katydid species for studies on the evolution and ecology of katydid communication and for future acoustic monitoring projects. Our research group is currently developing a phylogeny of the species in this study to assess the evolution of acoustic and vibrational signaling in Neotropical katydids. In addition, we are developing artificial intelligence approaches to automate the detection of signals in field recordings for acoustic monitoring and conservation projects. We hope that making these recordings freely available will allow other researchers to incorporate these data in additional studies and accelerate our understanding of the evolution, ecology, and conservation of these amazing insects.

Acknowledgements

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Supplementary material 1

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Data type: XLSX file

Explanation note: Excel spreadsheet with all call measurements described in the manuscript.

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Link: https://doi.org/10.3897/jor.29.46371.suppl1

Supplementary material 2

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Data type: XLSX file

Explanation note: Excel spreadsheet with the mean mass for each species reported in the manuscript and the statistical analysis of the relationship between mass and call peak frequency.

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